JURASSIC PARK GETS REAL HOW TO BRING BACK EXTINCT ANIMALS P.40

POPULAR SCIENCE

JUNE 2015

AMERICA'S SECRET SPYPLANE

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A LAZY HACKER'S GUIDE TO FITNESS

NO SWEAT!

+

SAVIOR OR SNAKE OIL?

THE BOOMING BUSINESS OF STEM CELL THERAPIES

THE FUTURE OF ENERGY

11 BRILLIANT IDEAS TO POWER THE PLANET

PLUS!

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LONG LIVE THE MAMMOTH
Scientists have the tools to bring back extinct species. Here's how they plan to do it. **BETH SHAPIRO**
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ILLUSTRATION BY CHRIS BUZELLI

Featuring

AMERICA'S NEXT SPYPLANE
A secret hypersonic replacement for the legendary SR-71 promises to transform military aviation. **CLAY DILLOW**
PAGE 38

THE NEW FACES OF ENERGY
Entrepreneurs have been reinventing the way we make, store, and deliver power. Here are a dozen of the most innovative.
PAGE 46

THE CURE-ALL
Doctors say a new, unproven stem cell therapy can miraculously heal any number of ailments. **TYLER GRAHAM** investigates by undergoing treatment.
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ON THE COVER
The SR-72 will be the world's fastest spyplane. Illustration by **Don Foley**

From the Editor

Toward a Brighter Future

> IT'S AS IF WE SPENT THE PAST 10 YEARS LAYING THE FOUNDATION FOR A HOUSE, AND NOW WE'RE FINALLY READY TO BUILD.

A few weeks ago, our executive editor forwarded me an invitation to a discussion on the future of energy. From the sound of it, a bunch of engineers were gathering at a local bar to drink beer and delve into the nuances of base loads and grid smoothing. She wrote, “Cliff, this sounds like your idea of a great night out.” She was not being ironic—she was actually right on the mark.

Of the many things I geek out on (and oh, there are many), few are closer to my heart than energy. Steam power sparked the industrial revolution; electricity helped usher in the machine age; and oil and gas make possible our current era of globalization. With every innovation in how we harness and use energy, we, as a civilization, press forward. Which raises the obvious question: What's next?

Over the past decade, fracking has transformed the oil and gas industries, while solar and wind installations have grown almost exponentially. We now have access to more power, from more sources, than we've ever had. At the same time, we're using energy in new ways. We're storing it, so we can deploy it more strategically. We're consuming less of it (at least per capita here in the U.S.), thanks to LEDs and efficient appliances. And we're connecting it to the Internet, creating a network of smart infrastructure that will one day optimize itself.

In an industry as stodgy as energy, any one of these developments would be big news. Taken together, they represent a sea change. It's as if we spent the past 10 years laying the foundation for a house, and now we're finally ready to build. The developments we'll see next will be dramatic. This being *Popular Science*, we couldn't help but ask who, exactly, will drive them. After months of searching, we settled on 12 names.

The folks in our feature “The New Faces of Energy” work in various fields across the industry, as academics and entrepreneurs (or both). Some make software. Others make batteries. One is even making diesel fuel from discarded plastic—a Spanish factory is already using his method to process 20 tons of waste a day.

All together it's a remarkable group, but more to the point, it's a glimpse at the future—one, I might add, that's looking brighter all the time.

Enjoy the magazine.

Cliff Ransom
Editor in Chief

Contributors

Tyler Graham
After years of back pain from snowboarding spills and endless desk work, writer Tyler Graham tried a new and unproven stem cell treatment. He wrote about his experience in “The Cure-All” (page 58). Graham knew it was risky, but so far, so good. “I feel great, but sometimes I hear Donald Rumsfeld's voice echoing in my brain,” he says. “When it comes to stem cells, what are the unknown unknowns?”

Sarah Charley
Sarah Charley majored in chemistry in college but was more interested in writing than lab work. An early assignment left her fascinated by particle detectors. “They let us look into a world that's impossible to see otherwise,” she says. With help from the European Organization for Nuclear Research, she created instructions for a DIY version in “Build Your Own Particle Detector” (page 71).

Marius Bugge
“Most people hate having their picture taken, so I try to make them relaxed,” says Marius Bugge, who photographed the subjects for “The New Faces of Energy” (page 46). The shoots took place on both U.S. coasts and in Dublin—a logistical nightmare. “We had to race six hours down the coast, from Oregon to San Francisco, for one shoot,” he says, but the visit to Dublin “more than made up for it.”

Beth Shapiro
Evolutionary biologist Beth Shapiro works with ancient DNA, a field that has produced insights into the lives of extinct species. “But whenever I got a call from a family member or a journalist, it was always: ‘Does this mean we can clone a mammoth?’” she says. “There is no soundbyte-size answer. So I decided to write a book.” She adapted an excerpt from it for “Long Live the Mammoth” (page 40).

RANSOM: MARIUS BUGGE; COURTESY CONTRIBUTORS

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15K Estimated milligrams of caffeine in all the items on page 36—that's the same as about 158 cups of coffee

Bet you didn't know...

It would take 38 minutes to fall through a (hypothetical) hole from one end of the Earth to the other. Until recently, it was thought to be 42 minutes.

What Have You Been Tossing in the Ocean?

While reporting on ocean plastic (page 32), we came across a report by the Ocean Conservancy that highlighted the strangest debris found on the planet's shores.

Some of our favorites:

- A 1904 typewriter
- A lava lamp
- A working iPad
- A plastic eyeball
- A trampoline
- A washing machine

Q WHAT EXTINCT SPECIES WOULD YOU BRING BACK?

1. The passenger pigeon, because it must have been delicious.

2. Anything but the passenger pigeon. The flocks were millions-strong and would block out the sun for hours as they passed overhead. Terrifying.

3. I'd bring back the moa, because what other bird has quads bigger than a tennis player's?!

4. The giant ground sloth. If you like watching sloth videos on YouTube, imagine seeing its ancient cousins.

5. Dire wolves. *Game of Thrones* makes them seem like good pets.

MISTAKE OF THE MONTH

An explosion in a drum containing nuclear waste last year is being blamed on cat litter. For years, lab workers have used it to soak up liquid nuclear waste. However, Los Alamos National Laboratory switched from an inorganic clay litter to an organic one called Swheat Scoop, which didn't play nice with the nitrate salt residue and neutralization agent.

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Peer Review

WALKING THE WALK

I read your article about taking a fish for a walk ["Teach a Fish to Walk," April 2015]. In Pennsylvania I once caught a catfish, took it off the hook, and set it down on a rock. Believe it or not, when I turned back to pick up the fish, it was standing up and very slowly walking across the rock. It was incredible. I haven't been able to keep any catfish after that afternoon.
Steve Kuzma, Corry, Pa.

A BETTER BASEBALL

Q: I'm surprised that in the description of the flat-seamed baseball ["How It Works," April 2015] there was no mention of the effect on pitches. Aren't the seams what cause a ball to curve or slide because of the way they affect the air flowing over the ball?
Alan Bronstein, Elkins Park, Pa.

A: The flatter seams probably won't have much of an effect on specialty pitches because the pitcher-imparted spin is dominant. Backspin is the reason you get a rising fastball; sidespin is why you get a curveball. The stitched seams do have an aerodynamic effect, but it's an effect on drag, not directionality. The lower seams really pay off for the 100-plus mph hit ball. So pitchers won't notice as much of a difference with the flat-seamed balls as batters (and fielders) do.
Jenn Stroud Rossmann, associate professor and head of the department of mechanical engineering at Lafayette College, Easton, Pa.

NERDY TWEET OF THE MONTH

Sodium sodium sodium sodium sodium sodium sodium sodium sodium sodium sodium sodium sodium sodium sodium sodium Batman! @GroundedReason

ON THE BRIGHTER SIDE

In the April 2015 article "The Dark Web Revealed," Marc Goodman lists almost exclusively the negative aspects of this portion of the Web and none of its positive ones. The Dark Web was started by our government and paid for with tax dollars, and it can provide a modicum of privacy for the average citizen writing an email or doing research with a search engine.
William King, Poinciana, Fla.

NOT-SO-CLEAN TECH

Your claim that fuel-cell vehicles are the "white whales of the clean-vehicle set" ["How It Works," April 2015] overlooks the fact that hydrogen is not a fuel source but rather a means of conveying power, like a battery or fuel tank. Hydrogen is normally produced from natural gas through a very inefficient process. Stripping it from water requires even more energy. This source of automobile power does not reduce emissions; it merely transfers them from tailpipes to generating stations and, with the inefficiency inherent in multistep processes, may even increase emissions in total.
Rick Geddes, North Augusta, S.C.

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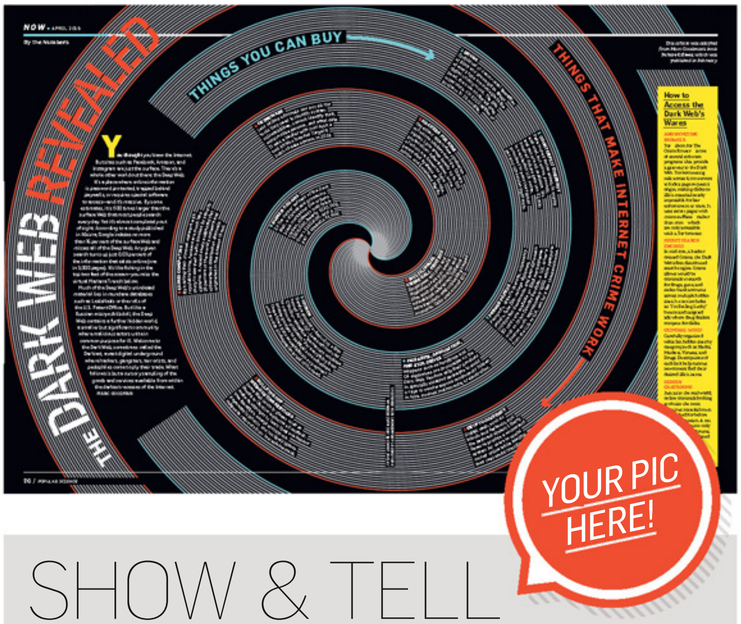

SHOW & TELL

In this issue, we showcase absurd robots built to perform pointless tasks (page 68). Send us a picture of the most senseless machine you've encountered, and tell us what it's designed to do. Email *showandtell@popsci.com* or tweet @popsci #showandtell.

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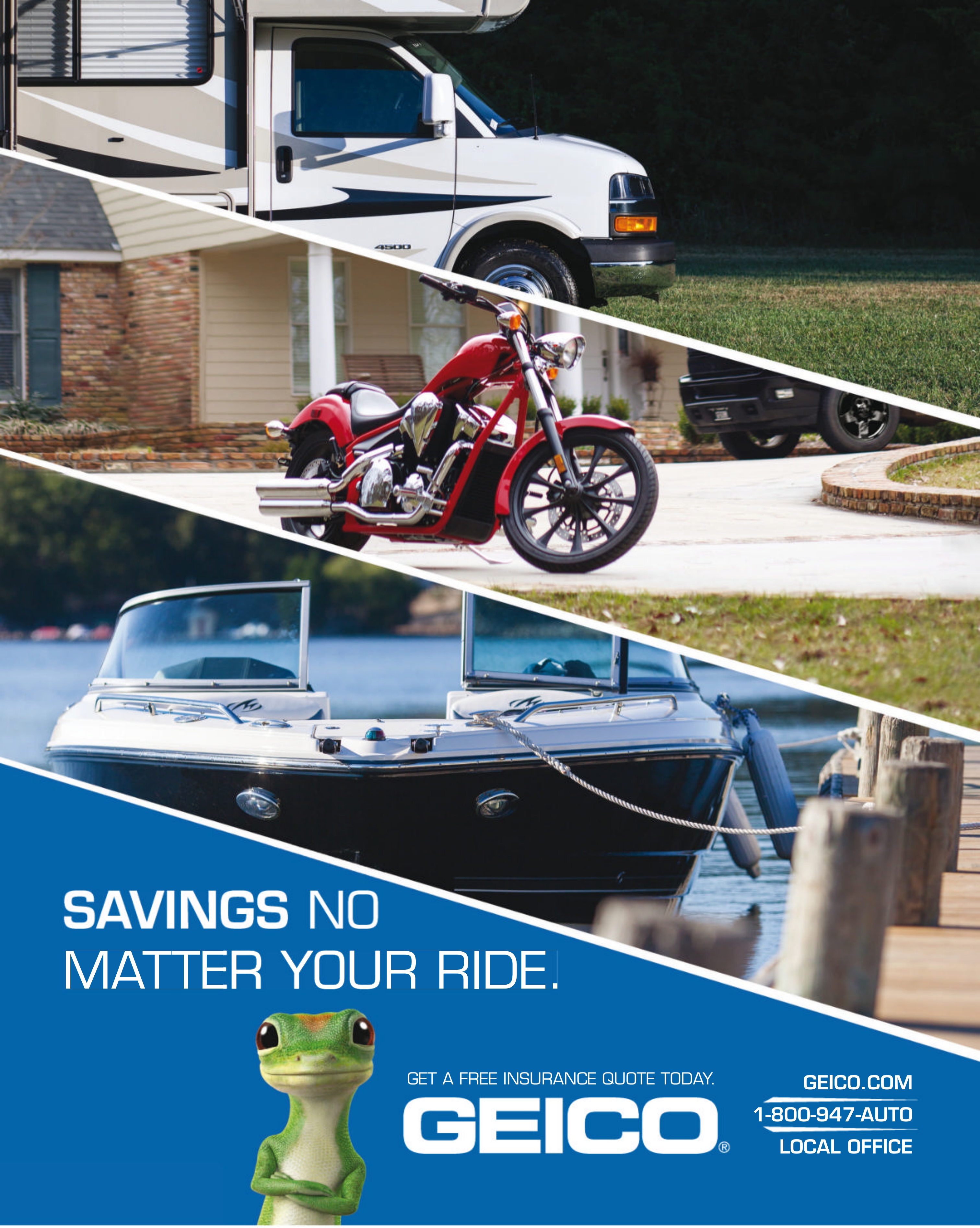

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Now

EDITED BY *Michael Nuñez & Lindsey Kratochwill*

A Grill That Talks Back

Searing steaks and veggies to perfection is a burden when you're trying to chat with guests—or disappear into the den for a few innings. Luckily, the grill obsessives at Lynx have devised a way to get you off the hook. Their new SmartGrill is a voice-controlled, Wi-Fi–connected, app-driven stainless-steel cooker that takes your order and executes it with precision. Start with a command: "SmartGrill, sear some radicchio." The grill selects a recipe from its online database and fires up the burners to the right temperature. It tells you where to place the food, and then automatic temperature-sensing probes work with motorized gas valves to ensure everything cooks evenly. When done, the grill shuts off the burners and sends you a text message. In time, its brain, an embedded microprocessor, will also learn your preferences. So if your idea of medium-rare is a little pinker than average, that's exactly what you'll get. **MICHAEL NUÑEZ**

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PHOTOGRAPH BY *Sam Kaplan*

Obsessed

Some things are just ... better

LINDSEY KRATOCHWILL

1 COOLBOX
For all the innovations in tool design, the humble box to house them has remained, well, a box. Coolbox not only stores hammers and nails; it also has a tablet stand, built-in battery, LED lights, and even Bluetooth speakers. **$179**

2 MIPOSAUR
WowWee's newest self-stabilizing bot has teeth and talons. But this toy is far from frightful—MiPosaur plays with, guards, and chases a little ball using the company's BeaconSense technology. If you have a few MiPosaurs, they'll play with each other too. **$120**

3 TACTUS PHORM
Tactus's iPad mini case snaps onto your tablet and uses microfluidic channels to expand a top layer of polymer. The result: your cold, unfeeling touchscreen morphs into a tactile keyboard. **$149**

4 LEATHERMAN TREAD
Leatherman is getting on board with wearables. The stainless-steel Tread multitool is wrist worn and becomes a box wrench, screwdriver, bottle opener, and plenty more. **From $150**

5 *INFESTED*
Whether it's feasting on blood or invading dreams, the bedbug has disturbed sleepers for millennia. Contributing editor Brooke Borel navigates the history and science of the legendary pest in her debut book. **$26**

6 CARDS AGAINST HUMANITY SCIENCE PACK
Cards Against Humanity teamed up with science writer Phil Plait and Web comic writer Zach Weinersmith to make the Science Pack. This add-on to the ridiculously popular party game comes with 30 new cards. Each purchase of the new deck supports a scholarship program for women pursuing undergraduate STEM degrees. **$10**

7 TINKERPLAY
With Autodesk's new app (available on iOS, Android, and Windows), kids can bring imaginary creatures to life, or at least 3-D print them. Novice makers can build by dragging and dropping interlocking parts. **Free**

8 ASYM ENERGY BOOST
A left-handed golfer wouldn't tee off with a right-hander's club. With that in mind, Adidas designed a golf shoe specific to the player's dominant hand. During a swing, the asymmetrical cleat pattern adds stability and grip only where they're necessary. **$300**

9 HUE GO
Outdoor shindigs need illumination come nightfall. Philips turned its Hue smart bulb into a portable, battery-powered light. It lasts three hours on a charge and, like the smart bulb, changes colors and works with more than 300 third-party apps. **$100**

TOUGH & TRENDY

1

2

3

4

BROOKE BOREL
INFESTED
HOW THE BED BUG INFILTRATED OUR BEDROOMS AND TOOK OVER THE WORLD
5

6

7

8

9

10 *JURASSIC WORLD*
After 22 years, the dinosaurs are back (again). It's a familiar scene: a theme park, genetically engineered hybrid reptiles, Steven Spielberg. What could go wrong? If you're still holding out hope for a happy ending—or just want to see the inevitable carnage on the big screen—go see it for yourself. **June 12**

CLOCKWISE FROM TOP LEFT: COURTESY WOWWEE; COURTESY COOLBOX; COURTESY TACTUS TECHNOLOGY; COURTESY CARDS AGAINST HUMANITY; COURTESY PHILIPS; COURTESY UNIVERSAL PICTURES; COURTESY ADIDAS; COURTESY UNIVERSITY OF CHICAGO PRESS; COURTESY LEATHERMAN; COURTESY AUTODESK

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Your Next $2 Million Ride

When it comes to high-end vehicles, Swedish automaker Koenigsegg is known for pushing boundaries. Now it has done away with one of the hallmarks of a sports car, the clutch. Its new hybrid, the Regera, can go from zero to 250 miles per hour in under 20 seconds—without a conventional transmission.

The Regera (which means “to reign” in Swedish) combines a powerful V8 twin-turbo engine with three electric drivetrain motors: one at each rear wheel and one at the engine’s crankshaft. The electric motor at the crankshaft drives the car from a dead stop to about 20 miles per hour. Then, the 1,100-horsepower engine kicks in.

It powers the rear wheels via a single gear, what Koenigsegg is calling Direct Drive. This reduces the type of power loss seen in transmission drivetrain by more than 50 percent. It also makes the car lighter, more responsive during acceleration, and more fuel-efficient.

The Regera is not the first hybrid to forgo a transmission (Honda’s 2014 Accord Hybrid beat Koenigsegg to the punch), but it is the first combustion-engine car to do so. This means there’s less reason to fear that high-performance vehicles will be legislated out of existence by fuel-economy and emissions standards.

MATTHEW DE PAULA

KOENIGSEGG REGERA

Zero to 60 2.5 seconds

Horsepower more than 1,500

Price $1.89 million

CAR NEWS YOU SHOULD CARE ABOUT

1 Producing hydrogen fuel from raw biological material may soon be cheaper and easier. A team of Virginia Tech researchers have developed a method of extracting hydrogen molecules from readily available corn stover (leftover stalks, cobs, and husks).

2 More cars will soon see in the dark, according to auto-parts supplier Autoliv. The company predicts sales of its thermal night vision, which can detect objects up to 150 feet in front of the car, will grow from 80,000 units sold last year to as many as 300,000 by 2020.

3 General Motors, Ford, Nissan, and Volkswagen are racing to sell affordable electric vehicles that can break 200-miles on a single-charge within the next three years. The companies believe that breakthroughs by major battery suppliers such as LG Chem could increase demand.

4 Garmin’s new portable navigation device does more than tell you where to turn. The nüviCam LMTHD comes with a built-in dash cam similar to those found in luxury vehicles. It alerts drivers if they’re too close to the car ahead or drifting from their lane. It’s on sale for $400.

277 Estimated annual cost, in billions of dollars, of motor vehicle crashes according to the Department of Transportation. Costs include property damage, lost productivity, medical fees, and more.

DESIGN OF THE MONTH

Aston Martin DBX Concept

The British automaker’s new DBX looks like a DB9 sports car with seating and wheels raised to SUV heights. The result is a high-riding coupe ready for superhero comic-book duty—or a luxury drive in the country. The two-door all-wheel-drive vehicle fits four adults, has a trunk big enough to carry their luggage, boasts auto-dimming “smart glass,” and features a shark-like snout that just smirks coolness.

FRMO TOP: COURTESY KOENIGSEGG; COURTESY ASTON MARTIN

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*Based on IHS Automotive, Polk U.S. new total registrations for CY1987-April 2014 for VW competitive body styles (Sedan, Coupe, Hatchback, Convertible, Station Wagon, SUV). Excludes Vans and Light Trucks. **See www.fueleconomy.gov for EPA estimates. Your mileage will vary and depends on several factors, including your driving habits and vehicle condition. †765-mile range based on 29 highway mpg EPA estimates for a 2015 Touareg 3.0L TDI®, 8-speed automatic transmission and a 26.4-gallon fuel tank. 31 city/46 highway mpg (2015 Jetta 2.0L TDI® Clean Diesel, 6-speed manual transmission). 30 city/45 highway mpg (2015 Golf 2.0L TDI® Clean Diesel, 6-speed manual transmission). 31 city/41 highway mpg (2015 Beetle 2.0L TDI® 6-speed manual transmission). 30 city/40 highway mpg (2015 Beetle Convertible 2.0L TDI® 6-speed manual transmission). 30 city/44 highway mpg (2015 Passat 2.0L TDI® Clean Diesel, 6-speed manual transmission). EPA estimates. Your mileage will vary and depends on several factors, including your driving habits and vehicle condition. ©2015 Volkswagen of America, Inc.

The Setup

THE LAZY HACKER'S GUIDE TO FITNESS

Working out is tough. Activity trackers like the Nike+ FuelBand are good motivators, but they're bad at crunching important data. Some can fail to track calories burned by as much as 40 percent, according to a study last year from Iowa State University. Still, technology can help you lose weight and get in shape if you know what to use—and how to use it. Jump-start your summer fitness regimen with these tools. **AMANDA GREEN**

MAKE CARDIO COUNT

TANGRAM SMART ROPE

Boxers have long known that jumping rope works nearly every major muscle group. It also burns as many calories in 10 minutes as jogging an eight-minute mile. The Smart Rope syncs with your phone to make training recommendations (like when to speed up) and log calories burned. The rope's 23 LEDs display your progress as you jump, so you don't have to keep count of hundreds of revolutions. **$70**

SIT DOWN AND TONE UP

TAO WELLSHELL

Low-impact isometric exercises are among the most efficient ways to build strength—and you can do them at your desk. The WellShell is a handheld trainer that comes loaded with dozens of exercises, trackable on its app. Its pressure-sensitive casing can record the force of your reps and calories burned, putting a full-body workout at your fingertips. **Price not set**

BUILD LEAN MUSCLE

SKULPT AIM

Achieving symmetrical strength across the body is important but difficult. The Skulpt Aim gets you there. It uses electrical impedance myography (EIM) to measure muscle quality and fat percentage in the biceps, triceps, abs, and quads. Place it on target areas before and after exercise to find out precisely how strong you're getting. Generally, the ideal amount of body fat ranges from 14 to 17 percent for men and 21 to 24 percent for women. **$200**

CHECK YOUR HEAD

GAIAM MUSE

Getting in shape isn't all about back-breaking work. Research suggests that just 15 minutes of meditation increases concentration, reduces stress, and helps you cope with pain during and after exercise. The Muse headband measures brain activity with electroencephalogram (EEG) sensors while an app guides you through 12-minute meditation routines. It plays bird-chirping noises when you achieve a clear, relaxed state of mind and gusts of wind when it's time to lasso wandering thoughts. **$300**

While you're at it: Try the Saucony ISO Triumph. Its heel-to-toe differential is optimized for runners. →

PHOTOGRAPH BY *Sam Kaplan*

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Decode Your Air Quality

How much do you know about the climate inside your home? Humidity, volatile organic compounds (VOC), and barometric pressure? We thought so. That's where CubeSensors come into play.

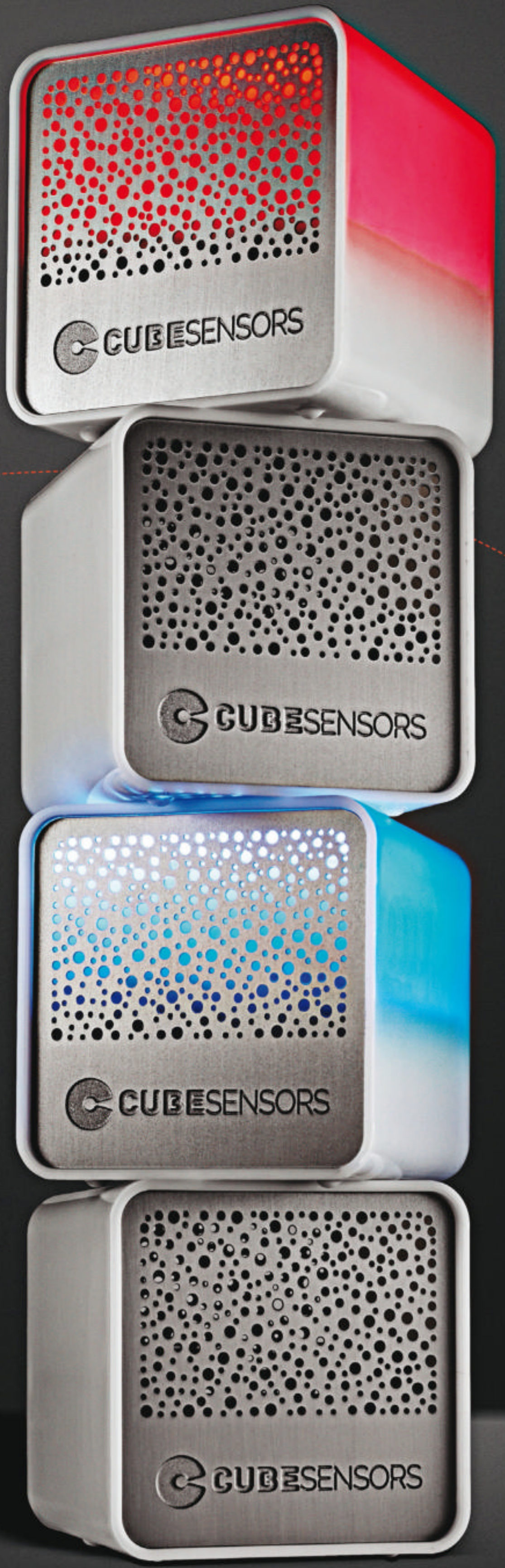
Palm-size and wireless, these wee boxes sniff out the tiniest changes in atmosphere, helping you assess the condition of any Wi-Fi–connected room.

Each set includes a base station that connects to a mobile app via a router or modem. To get a reading, shake the cubes. A blue glow means everything is fine. Red means you have a problem and need to check the app for details. Ultimately, you can combat allergies and (literally) breathe easier when you know what's in your air.

The cubes can also be paired with a Fitbit or Jawbone Up, allowing you to link sleep disruptions to environmental causes. If you snore, dry air could be the culprit. The app's recommendation: Turn on the humidifier. **JUNNIE KWON**

0.10

Parts per million (ppm) of formaldehyde that can cause coughing, wheezing, and eye irritation. One survey U.S. homes by the Environmental Protection Agency reported a range of 0.10 to 3.68 ppm.



CubeSensors come in packs of two, four, and six ($300 to $600).

VOC LEVEL

Volatile organic compounds are carbon-based chemicals that can easily evaporate at room temperature and enter the lungs. Examples include acetone, benzene, and formaldehyde, all of which can be found in building materials and personal-care products.

PHOTOGRAPH BY *Sam Kaplan*

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How the Raspberry Pi Sparked a Maker Revolution

EDITED AND CONDENSED BY
MICHAEL NUÑEZ

Three years ago, Eben Upton needed a cool gadget to lure students to his computer science program at the University of Cambridge. So he invented the Rasberry Pi. It has since become the cheapest hackable computer on the planet. He has sold five million (at $20–$35 a pop), released a faster version this February, and become an icon of DIY culture. Now, as Microsoft prepares to launch a Pi-friendly version of Windows, Upton is bracing for a wave of new users. He recently spoke with *Popular Science* about hacking, education, and his tiny creation.

Popular Science: Why does the world need Raspberry Pi?
Eben Upton: We wanted to build something affordable and programmable and fun and robust that kids would want to have in their lives. You know, it sucks being a kid. You have no power. You basically do what other people tell you to do for 18 years. The nice thing about computer programming is you have this venue in which you have power. You have agency. You have the ability to take charge, be in control, and build the thing you want to build. And kids like that maybe their parents don't understand it.

PS: What makes it so kid-friendly?
EU: [The appeal] is about hardware hacking and being able to build robots and stuff. We want you to be able to go to Facebook on the Raspberry Pi. We want you to be able to watch videos on it and play games. It's something fun enough that gets into a kid's life, but it's educational enough to teach them skills.

PS: Why didn't this exist 10 years ago?
EU: Ten years ago, you could build a $20 computer, but it wouldn't be interesting to kids. Now you can build a $20 computer and play *Minecraft*. You can build a $20 computer that will play a Blu-ray video. Plus, you can get free software tools.

continued on page 23 →

06

Number of times faster the Raspberry Pi 2 is than its three-year-old predecessor

PHOTOGRAPHS BY *Dan Burn-Forti*

continued from page 20 / **The Platform**

PS: What types of things are people making with their Raspberry Pis?
EU: This guy in the U.K. sends them [25 miles] up in balloons and takes big panoramic Earth photos. People attach them to telescopes to take space photos—we've seen amazing pictures of the moon. Someone's built a cellular base station with a Raspberry Pi. I think it's probably illegal to operate, outside of a sealed metal room, because most countries regulate who's allowed to be a cellular operator.

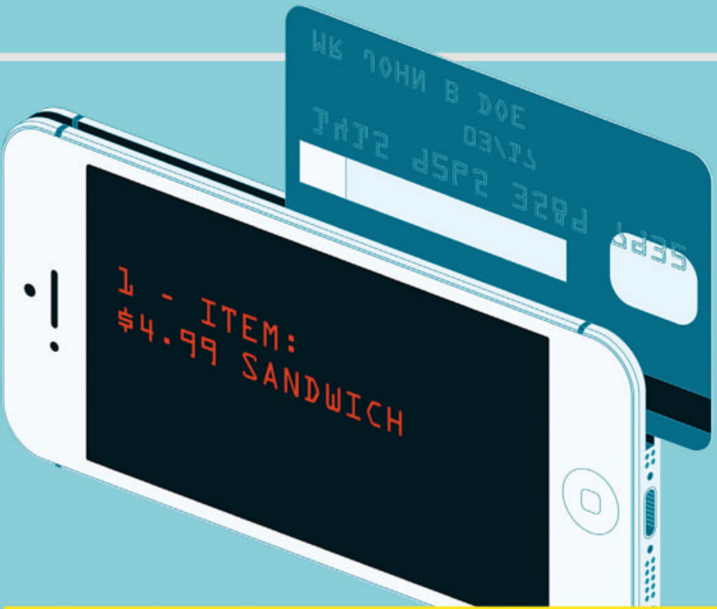
PS: You keep coming out with cheaper computers. Is your business plan just a race to the bottom?
EU: You can do two things with Moore's law: You can keep the price constant and add features, or you can keep the feature set constant and lower the price. Companies always like to do the former—they don't want to have their revenues decline year after year. What we feel we're doing is using Moore's law to save people money. We're going to make computing available to an entire swath of people who don't feel they can justify spending a few hundred dollars on a PC and don't need that level of performance anyway.

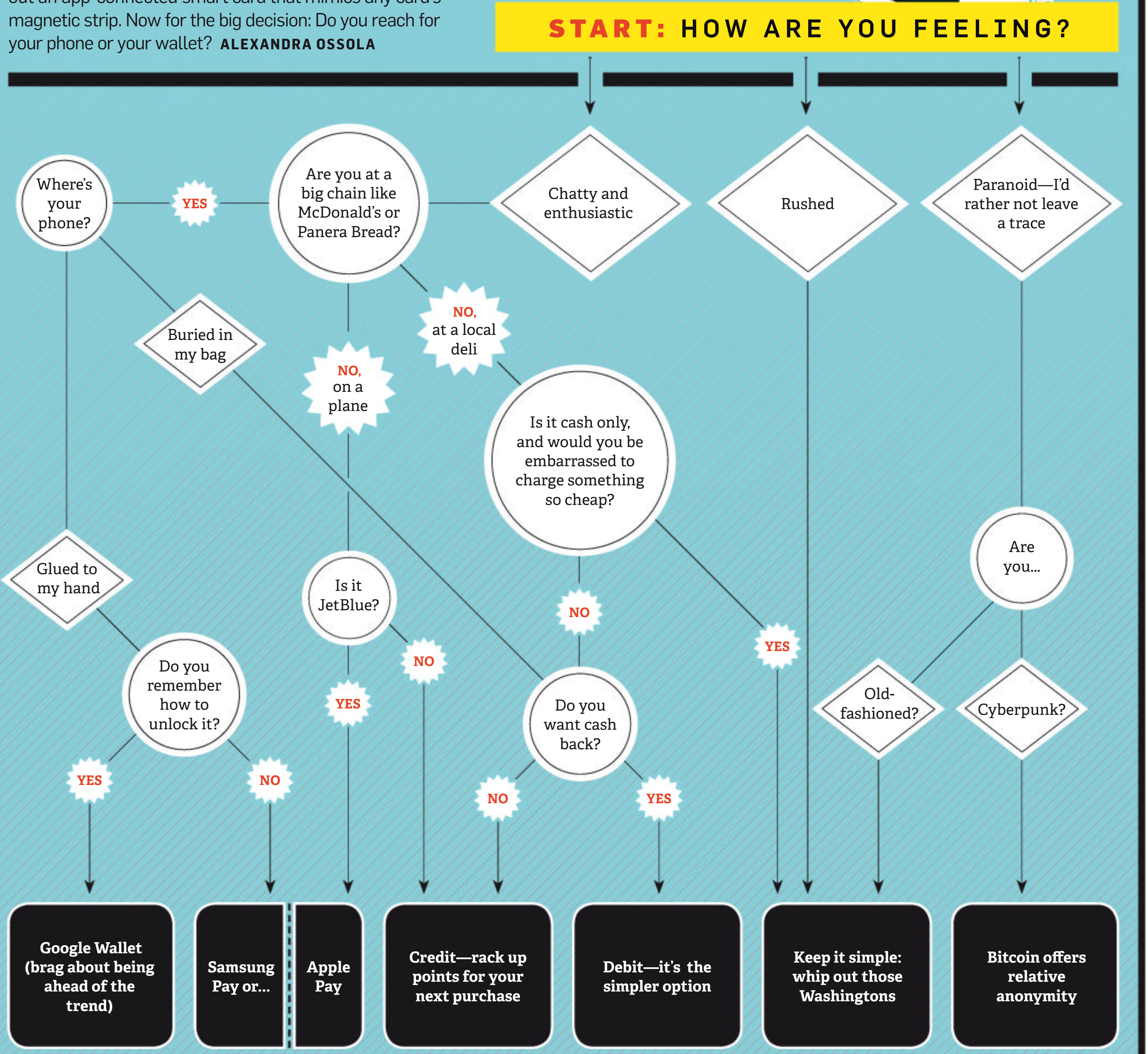
PS: You and your dad edited the *Oxford Rhyming Dictionary*. What was that like?
EU: Everyone should write a book with his dad. It's fun. My dad is a linguist. So effectively, I wrote a computer program to produce the rough draft of the dictionary. And my dad took that and turned it into the final product. It was a joint effort; we couldn't have done it without each other. His bit took him six months. My bit took me a couple of days. It's a great dramatization of what's great about computer programming—it's a labor-saving activity. [*Laughs*] P/S

Flowchart

How Should You Pay for That Sandwich?

Paying for things used to be simple: paper or plastic. But the new world of mobile payments brings your smartphone into the mix. Apple CEO Tim Cook promised that 2015 would be the year of Apple Pay, and other big players like Samsung, Google—and potentially Microsoft—hope to replace our billfolds. There's also CurrentC, which enables mobile payments using bar codes, and Stratos, which put out an app-connected smart card that mimics any card's magnetic strip. Now for the big decision: Do you reach for your phone or your wallet? **ALEXANDRA OSSOLA**

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Paranoid—I'd rather not leave a trace
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Glued to my hand
Do you remember how to unlock it?
YES
NO
NO, on a plane
Is it JetBlue?
YES
NO
NO, at a local deli
Is it cash only, and would you be embarrassed to charge something so cheap?
NO
YES
Do you want cash back?
NO
YES
Are you...
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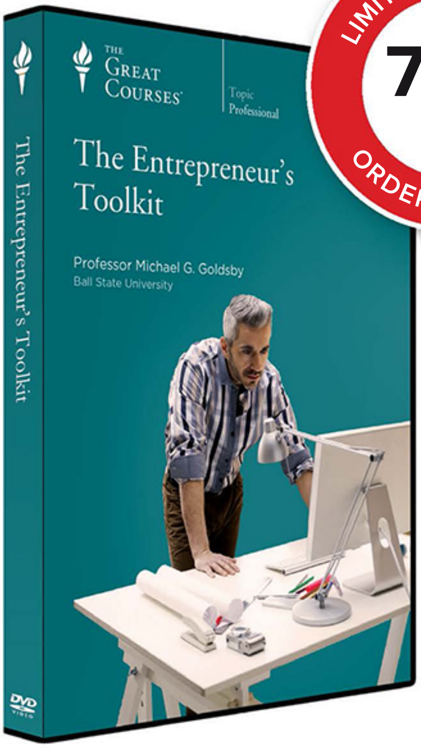
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Next

EDITED BY *Jen Schwartz & Breanna Draxler*

100K

Number of WIMPs scientists think pass through every square centimeter of Earth each second

A mile beneath Italy's Gran Sasso mountain lies the DarkSide-50 detector. The three-story cylinder was built to search for our universe's most mysterious substance: dark matter. "We know it exists in our galaxy and roughly how much there is," says Princeton physicist Peter Meyers. "What we don't know is *what* it is." The most promising lead is WIMPs—weakly interacting massive particles. If they do exist, these theoretical particles should drift through the walls of DarkSide-50's three nested tanks and collide with atoms of liquid argon at its core. The argon atoms would then recoil like billiard balls and emit light, providing proof of WIMPs and bringing us closer to figuring out dark matter's elusive identity. **SARAH SCOLES**

PHOTOGRAPH BY *Enrico Sacchetti*

Bryant Walker Smith

On the future of self-driving cars

For the first time, in March, an autonomous car drove itself from San Francisco to New York City. How is that even legal? That's the kind of question Bryant Walker Smith, an assistant professor of law at the University of South Carolina, tries to answer. He's an expert on the legal implications of self-driving cars. Smith sees a future in which these vehicles all but eliminate crashes, transform liability, and make us look back in horror at the risks we once took on the road.

40

Percentage of car-crash deaths that result from drunk or distracted driving—two things an autonomous car could never do

SOURCE: NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

“People ask me, 'Are you concerned about self-driving cars?' And I say, 'Yes, but I'm *terrified* of today's cars.' Thirty thousand people die every year on U.S. roads, and over a million are injured. Ninety-four percent of those crashes are caused by human error.

With self-driving cars, decision-making will no longer exist in real time. It's going to shift from a driver sitting behind the wheel, reacting impulsively, to teams of designers sitting behind computers, deliberately anticipating situations the vehicle may need to deal with. A lot of the liability will probably transfer to companies—the manufacturers, designers, and suppliers of the various driving systems. They'll likely be responsible for a greater share of the (hopefully much smaller) pie of total crash costs.

> “With automation, people will quickly zone out, so we have to decide what level of human engagement we can legally require.”

Cars will learn from experience too—they'll share enormous amounts of data with one another, getting collectively smarter over time. As with cellphones and the Internet, people will accept the technologies' benefits for some perceived loss in privacy. Far in the future, you'll get into a truly self-driving car and say, “I want to go to a good restaurant,” and you may not know, or care, where it'll take you. We'll still be vulnerable, just in a different way. A hacker could infect an entire model of car or corrupt a map or interfere with real-time vehicle communications in traffic. The question now is, how much of that risk are we willing to take in order to advance a technology that could potentially save a lot of lives?”

AS TOLD TO BREANNA DRAXLER

PHOTOGRAPH BY ***Aaron Greene***

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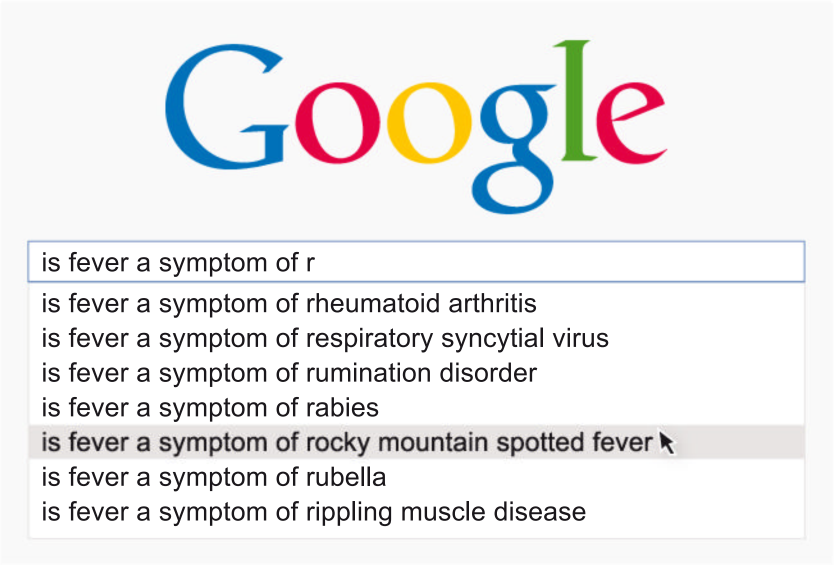


is fever a symptom of r

is fever a symptom of rheumatoid arthritis
is fever a symptom of respiratory syncytial virus
is fever a symptom of rumination disorder
is fever a symptom of rabies
is fever a symptom of rocky mountain spotted fever
is fever a symptom of rubella
is fever a symptom of rippling muscle disease

GOOGLE FLUNKS OUT OF MEDICAL SCHOOL

The search engine is releasing curated health information, but it doesn't solve our self-diagnosis problem

When faced with a strange ache or rash, many of us turn to the Internet for a diagnosis, rather than a doctor. That rarely goes well. (It's Rocky Mountain spotted fever! No, shingles! Leprosy?) To ensure that at least some credible information rises to the top of the results page, Google recently added a medical component to Knowledge Graph, its new research tool. Search for one of the 400 or so medical topics included in the Graph, and a set of facts vetted by a team of doctors and experts will appear in a big box on the right side of the screen.

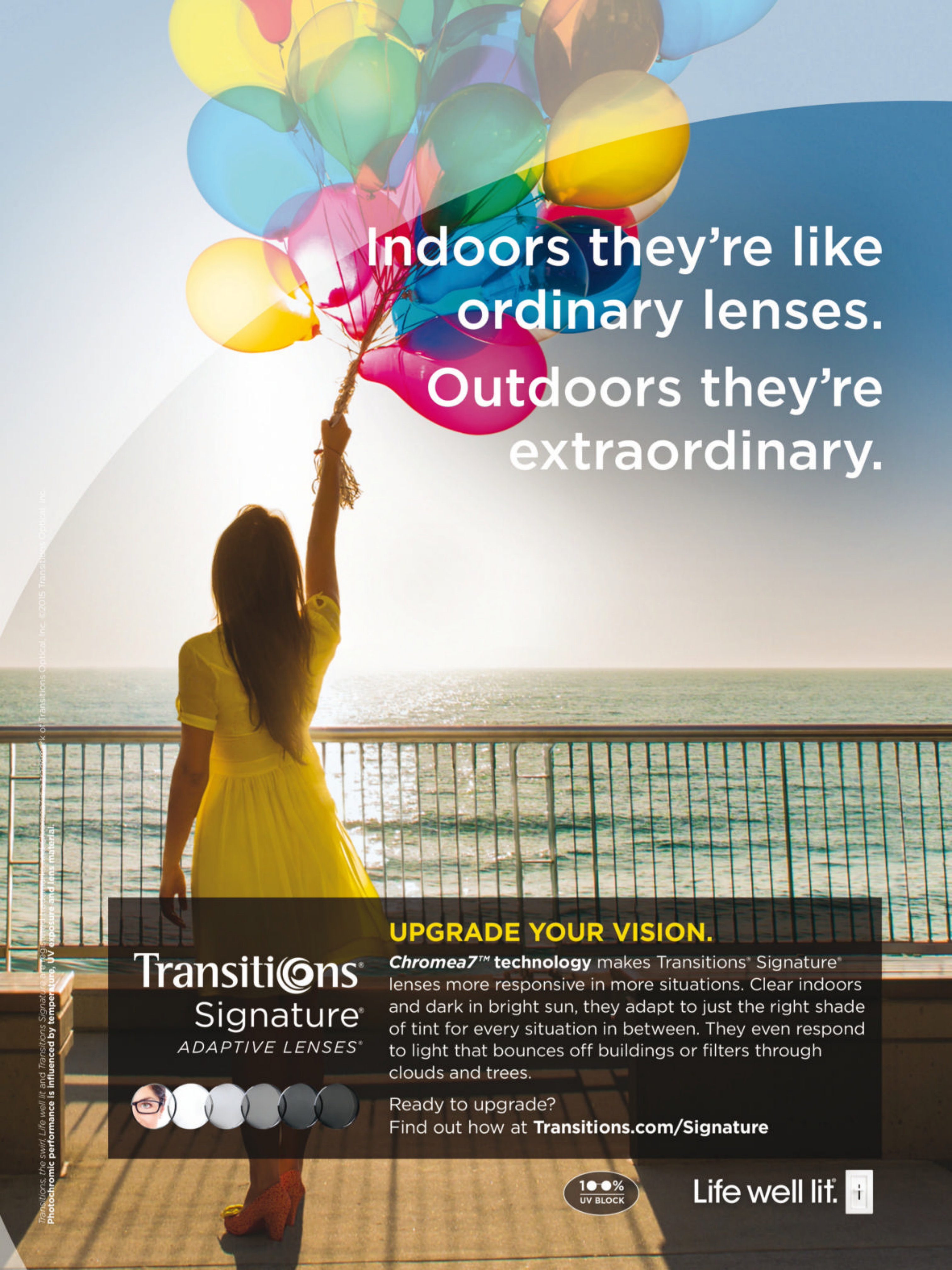
At first glance, the content—common symptoms, typical treatments—doesn't seem much different from what you'd find combing through reputable sources on your own. That's because the information was crowdsourced from hundreds of physicians across the country and fact-checked by a panel of doctors at the Mayo Clinic, says Prem Ramaswami, a product manager at Google. "Each fact is validated by 11 doctors—it's a consensus opinion," says Kapil Parakh, a cardiologist and public-health expert who's working on the Graph. "You're not getting anything cutting-edge." Google's innovation is that curated, accurate information is now the most prominent result users see.

And that's pretty much where the usefulness of Knowledge Graph ends. If the folks at Google wanted to create a medical encyclopedia, they might have used far fewer resources and just promoted results from the National Institutes of Health, for example. Knowledge Graph doesn't address the underlying problem: the way we actually research our health symptoms, which is usually late at night and scared, falling down a rabbit hole of journal studies, conflicting data, and naturopaths' blogs. Not good.

What the Internet really needs is a trusted voice to flag misinformation.

What would be truly useful is a smart filter that counteracts hype, eases fears, and helps separate fact from fiction amongst the wide range of results. Ideally, when someone searches for "measles" and "vaccine" and "autism," it should immediately become apparent that no credible studies link the three. It's a tall order, but what the Internet really needs is a trusted voice to flag medical misinformation before it can spread.

CHRISTIE ASCHWANDEN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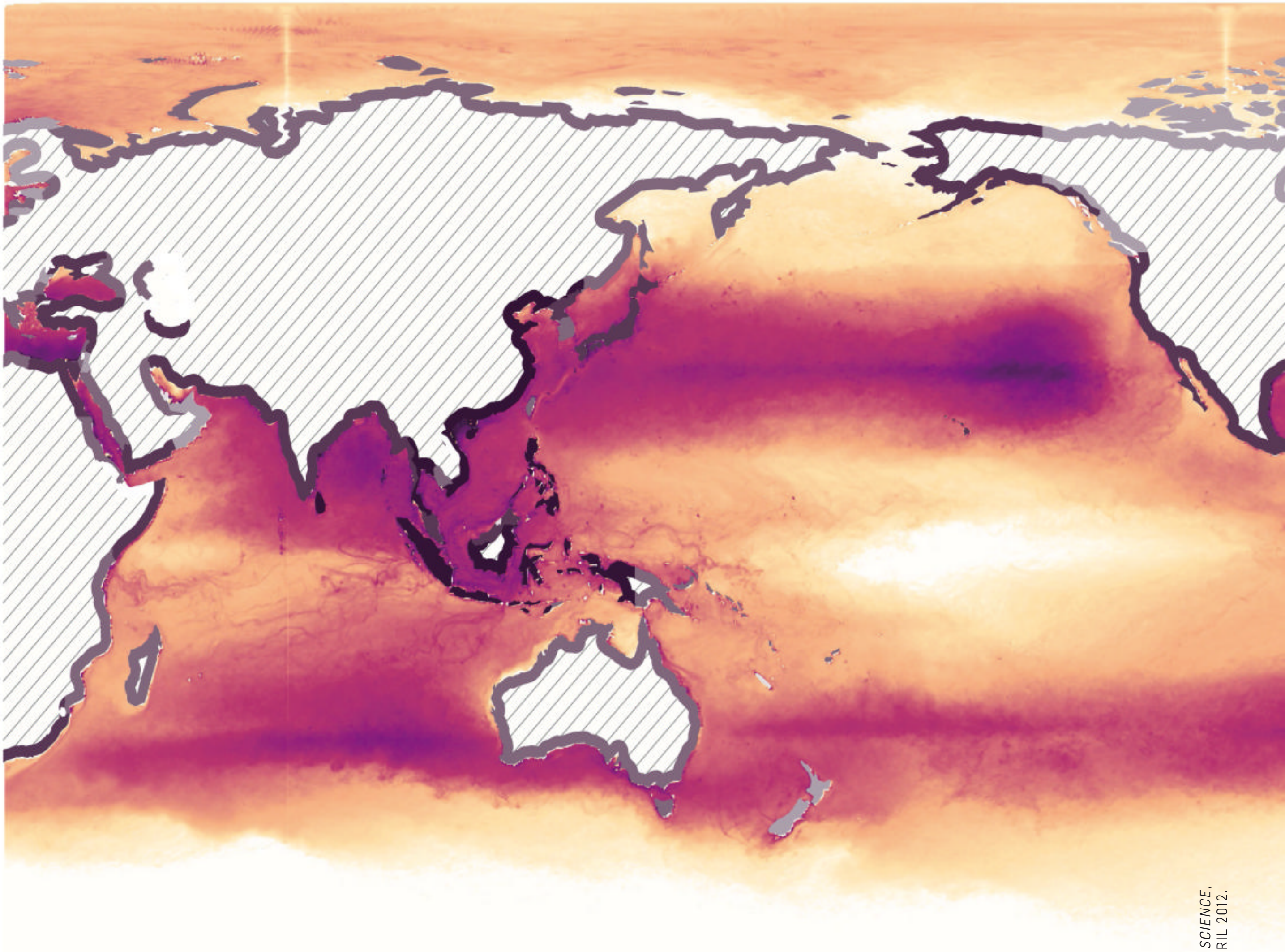


SOURCES: ERIKSEN ET AL., *PLOS ONE*, DECEMBER 2014; JAMBECK ET AL., *SCIENCE*, FEBRUARY 2015; KUKULKA ET AL., *GEOPHYSICAL RESEARCH LETTERS*, APRIL 2012.

There are Now Five Trillion Pieces of Plastic Floating in an Ocean Near You

In December, a consortium of 12 research institutions published some of the first numbers on global ocean plastic pollution. By their calculation, almost 300,000 tons of plastic swirl near the surface of our seas today—equivalent to the weight of about 1,500 blue whales.

"The ocean is covered in a thin layer of plastic," says Marcus Eriksen, director of research at the Five Gyres Institute. "It's like a plastic smog." The pieces resemble confetti and are so dispersed they're almost imperceptible, even when they collect in slowly rotating gyres.

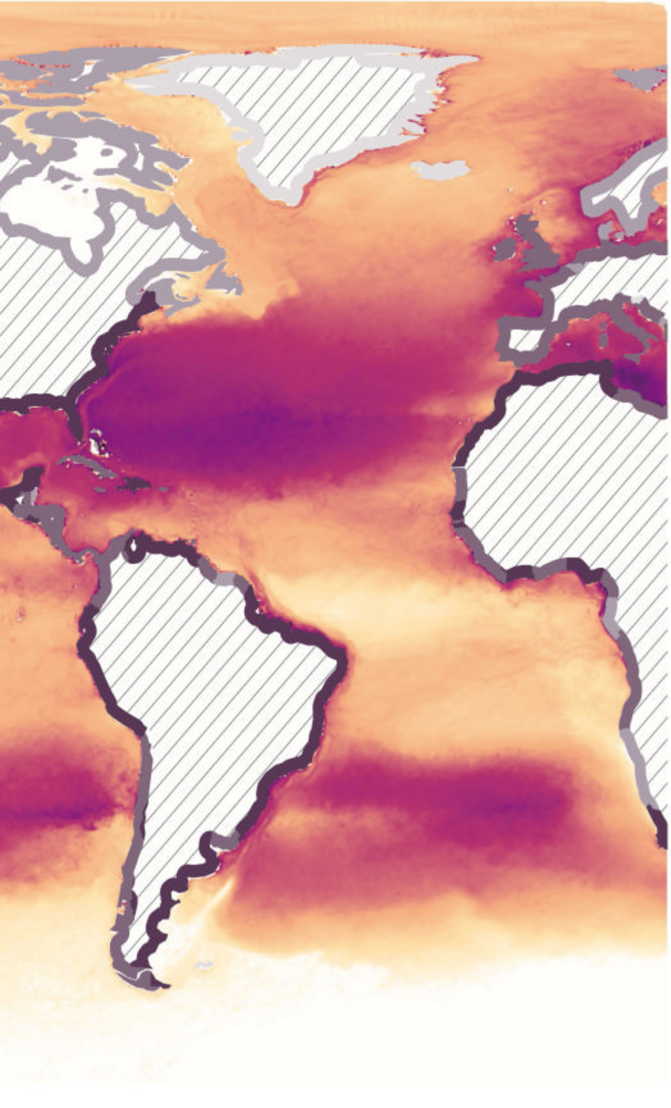
Still, the estimate is lower than expected. It doesn't include plastic that has sunk to the seafloor or been eaten by animals, for example. Some scientists think far more plastic—to the tune of five million tons—makes its way from our shores into the oceans every year.

11

Percentage of the world's waste that is made of plastic

To figure out where all this plastic is coming from, University of Georgia environmental engineer Jenna Jambeck and colleagues recently assembled a model that shows potential points of origin. And in a business-as-usual scenario, the model shows that plastic flow will double in the next decade. So the moment to slow the influx—and engineer ways to clean up the existing mess—is now. **CHRISTIE WILCOX**

DATA VISUALIZATION BY *Katie Peek*



NERD BOX The map combines two new models: one that shows the locations of plastic and one that shows its origins.

WHERE PLASTIC GOES
By sampling at nearly 1,600 points and combining that data with an ocean circulation model, Eriksen and colleagues estimate surface waters hold some 296,000 tons of plastic. Their model also pinpoints where the pieces are collecting.

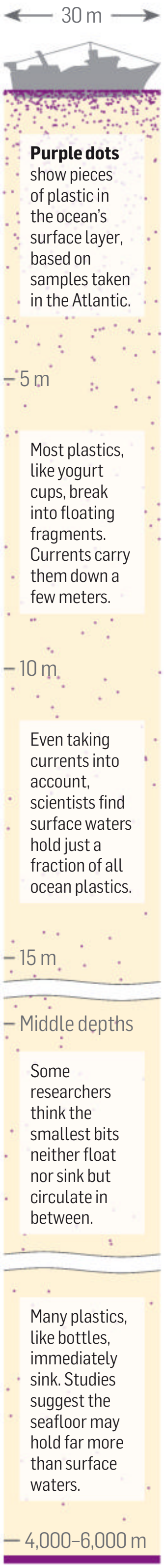
Estimated density of plastic, in grams per square kilometer

1 10 100 1,000 10,000 100,000 1 million

WHERE IT COMES FROM
By combining coastal population figures with plastic consumption and waste-management data, Jambeck models where plastic most likely originates. China tops the list.

Annual plastic loss by country, 50 kilometers in from coast

0 tons 1,000 10,000 100,000 1 million 2 million



Purple dots show pieces of plastic in the ocean's surface layer, based on samples taken in the Atlantic.

Most plastics, like yogurt cups, break into floating fragments. Currents carry them down a few meters.

Even taking currents into account, scientists find surface waters hold just a fraction of all ocean plastics.

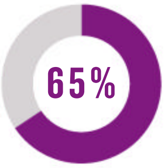
Some researchers think the smallest bits neither float nor sink but circulate in between.

Many plastics, like bottles, immediately sink. Studies suggest the seafloor may hold far more than surface waters.

HOW TO DEAL WITH THE DEBRIS (OR NOT)

OUT AT SEA

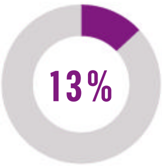
The trillions of plastic pieces in our oceans are incredibly spread out. "There's not a persistent patch that you can go mine for trash," Eriksen says. But the recent findings, paired with new circulation models, can streamline efforts to locate it. For example, nonprofit tech developer The Ocean Cleanup wants to use ocean currents to corral plastics into an array of anchored booms to concentrate and remove them.



Ocean plastic, by weight, that lies north of the equator

ON THE BEACH

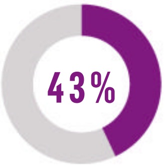
Easier than trying to recover these practically irretrievable bits of broken-down plastic is keeping plastic stuff out of the water in the first place. In 2013, volunteers with the Ocean Conservancy's International Coastal Cleanup collected more than 12.3 million pounds of beach trash around the globe, including more than 940,000 plastic bottles.



Collected trash comprised of plastic bottles or their caps

AT THE SOURCE

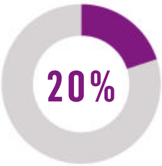
Better yet, let's curb plastic use altogether. The average American throws out 185 pounds of it every year. So while regulation may not be the sexiest approach to reducing waste, it's likely the most tenable. After San Jose, California banned plastic bags, in 2012, bag litter choking the city's storm drains dropped by almost 90 percent; it fell 60 percent in creeks and rivers. (Remember, those feed into the Pacific.)



Shoppers in San Jose who use no bag at all, up from 19 percent before the ban

BEYOND OUR REACH

Plastic's interactions with sea life are more mysterious. Some species benefit: Barnacles and bivalves colonize floating plastic debris to create novel ecosystems. But sea turtles and sea birds die from eating plastic that clogs their digestive tracts. The biological impact of marine plastics, and how animals affect their movement in the water, are the next big questions scientists are striving to answer.

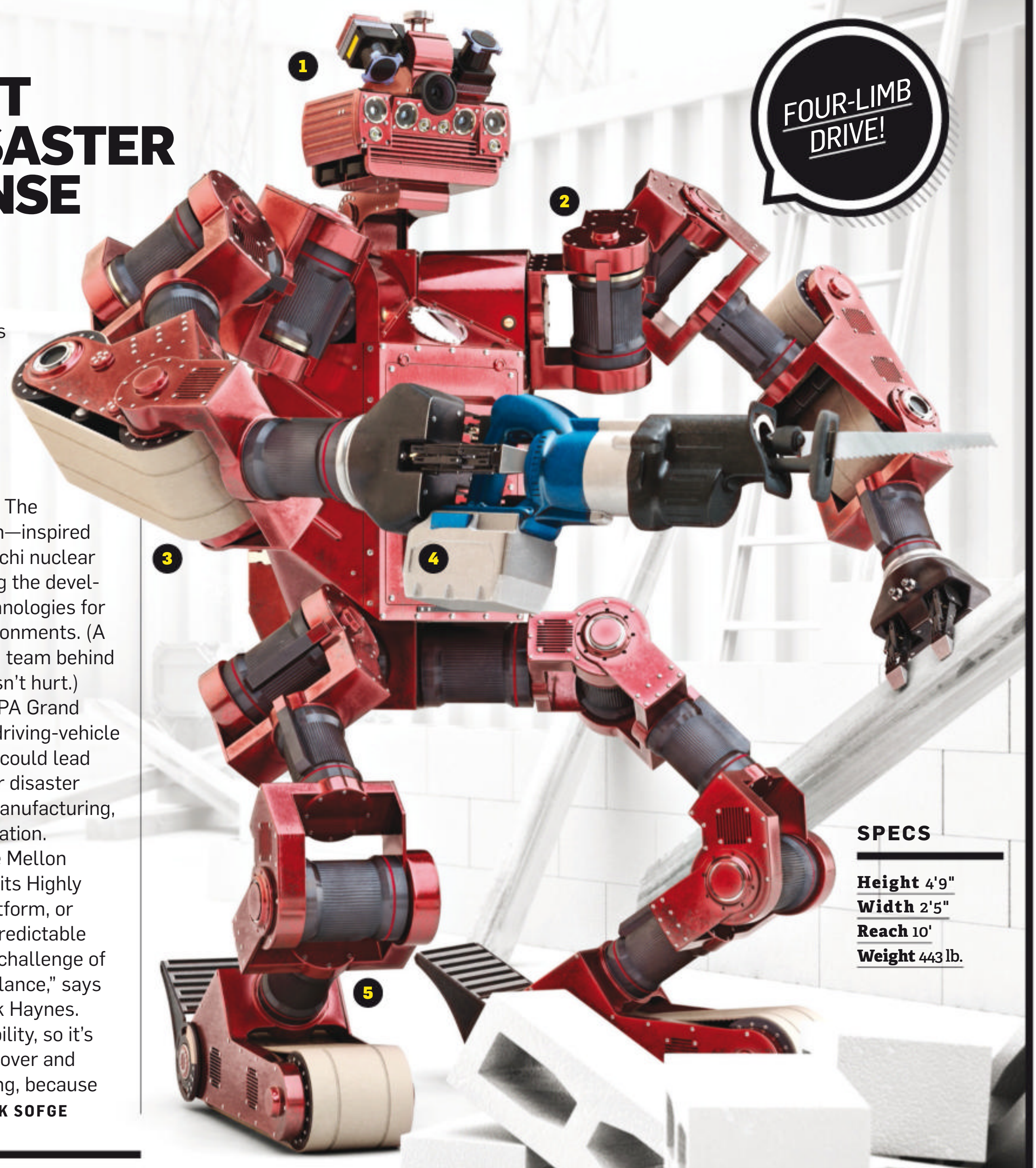


Rough estimate of small fish with plastic in their bellies

A ROBOT FOR DISASTER RESPONSE

This month, 25 robots will traverse rubble, saw through walls, and drive a vehicle through a simulated disaster zone in the DARPA Robotics Challenge final showdown. The three-year competition—inspired by the Fukushima-Daiichi nuclear accident—is motivating the development of robotic technologies for use in hazardous environments. (A $2 million prize for the team behind the winning robot doesn't hurt.) Just as the 2004 DARPA Grand Challenge led to self-driving-vehicle technology, this event could lead to dexterous robots for disaster response, advanced manufacturing, and warehouse automation.

A team at Carnegie Mellon University engineered its Highly Intelligent Mobile Platform, or Chimp, to excel in unpredictable terrain. "The greatest challenge of humanoid robots is balance," says head of software Clark Haynes. "Chimp has static stability, so it's never at risk of falling over and never actively balancing, because it doesn't have to." **ERIK SOFGE**



SPECS

Height 4'9"
Width 2'5"
Reach 10'
Weight 443 lb.

① SITUATIONAL AWARENESS Chimp can operate without human intervention but is most effective when it takes remote orders. Six cameras and lidar (like radar but with light) provide an operator with a 360-degree view of the robot's surroundings.

② STRATEGIC SLOUCH The robot's shoulders angle slightly forward, rather than sit in line with its torso, giving its 4.3-foot-long arms additional reach. The design also makes it easier to fit Chimp's stocky frame through doorways.

③ RUGGED MOBILITY Despite its humanoid "legs," Chimp doesn't walk. Instead, it rolls across terrain on rubberized tracks, like a tank. This reduces the risk of toppling over. In tough conditions, it can drop to all fours for more stability.

④ AUTONOMOUS MANIPULATION Spotty communications prevent a robot from relying on humans to control its "hands." Chimp can locate a valve or power tool with its computer vision, then use motion-planning algorithms to grasp and operate the object.

⑤ EFFICIENT BALANCE Chimp is statically stable, which means the robot doesn't need to use energy (or special software) to stay balanced. To save even more juice, it locks joints that aren't engaged. If the power is cut altogether, a parking brake freezes Chimp in place.

ILLUSTRATION BY Graham Murdoch

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Caffeine

The surprising downers of the planet's most popular stimulant

You've almost certainly taken the world's most commonly used psychoactive drug. In the U.S. alone, 90 percent of adults consume caffeine daily—often as coffee, but increasingly in the form of beverages, pills, snacks, and even pure powder. Global sales of energy drinks nearly doubled from 2008 to 2013. U.S. emergency-room visits linked to energy drinks doubled from 2007 to 2011, too. As consumption continues to surge and new products enter the market, scientists and regulators are racing to better understand how caffeine affects the human body. **JESSICA HULLINGER**

The caffeine molecule occurs naturally but is also made in labs

1

Seventy-three percent of U.S. kids consume caffeine on any given day, according to a 2014 *Pediatrics* paper; a Yale study found that middle-schoolers who imbibe energy drinks are at a 66 percent higher risk for hyperactivity than their peers who abstain. Kids' caffeine usage is also linked to depression and substance abuse.

2

Adults suffer too. Caffeine withdrawal was added to the *Diagnostic and Statistical Manual of Mental Disorders* in 2013. "It's seen frequently, often alongside anxiety disorders," says David Salvage, a New York psychiatrist who specializes in addiction.

3

Even more alarming is the growing popularity of powdered pure caffeine, readily available in bulk on eBay. In 2014, the Food and Drug Administration, spurred by two lethal overdoses, warned that people should avoid the stuff, but an outright ban is unlikely.

4

One teaspoon of powdered pure caffeine is equivalent to roughly 25 cups of coffee.

5

One of the barriers to safe consumption is that regulation is all over the place, says Murray Carpenter, author of *Caffeinated*. "If you put 200 milligrams of caffeine powder into a 5-hour Energy shot, it's regulated as a supplement," he says. But press it into a tablet, like NoDoz, and it's an over-the-counter medication. Blend it into six soft drinks and it's a food."

6

Even the military, which has long used caffeine-enriched foods to increase soldier alertness, is researching new methods for mental boosts, says Betty Davis, leader of the Performance Nutrition Team at the U.S. Army Natick Soldier Systems Center in Massachusetts. "We're looking to see if improving soldiers' gut health with dietary compounds is a good alternative," she says. Their findings could ultimately yield better, safer energy for the masses.

PROP STYLING BY SARAH GUIDO-LAAKSO AND MICHELLE LONGO FOR HALLEY RESOURCES

PHOTOGRAPH BY **Sam Kaplan**

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America's Next Spyplane

A secret, hypersonic replacement for the legendary SR-71 promises to transform military aviation

by Clay Dillow

Born in the spy-vs.-spy cauldron of the Cold War, the iconic SR-71 "Blackbird" remains the fastest air-breathing military aircraft the world has known. It flew so high and so fast that enemy defenses were powerless to intercept it. Eventually, satellite technology and advanced radar eroded its advantage. In 1998, the U.S. Air Force retired it. Now, with regional threats growing and portable surface-to-air missiles evolving, engineers have once again set out to build the fastest military jet on the planet.

This time, it will take the form of a 4,000-mile-per-hour reconnaissance drone with strike capability. Known as the SR-72, the aircraft will evade assault, take spy photos, and attack targets at speeds of up to Mach 6. That's twice as fast as its predecessor.

> "WE ARE NOW ON THE VERGE OF A HYPERSONIC REVOLUTION."
>
> —BRAD LELAND, LOCKHEED MARTIN'S HYPERSONIC PROGRAM MANAGER

Aeronautical engineers at Lockheed Martin and Aerojet Rocketdyne have been designing the SR-72 at their Skunk Works black site in California for the past several years. It will require a hybrid propulsion system: a conventional, off-the-shelf turbo jet that can take the plane from runway to Mach 3, and a hypersonic ramjet/scramjet that will push it the rest of the way. Its body will have to withstand the extreme heat of hypersonic flight, when air friction alone could melt steel. Its bombs will have to hit targets from possibly 80,000 feet. Lockheed says the craft could be deployed by 2030. Once it is, the plane's ability to cover one mile per second means it could reach any location on any continent in an hour—not that you'll see it coming.

ILLUSTRATION BY *Don Foley*

The SR-72 will travel at six times the speed of sound—the fastest military jet ever made—and fly as high as 80,000 feet.

1

PROPULSION

Turbojet engines can take a plane from runway launch to about Mach 3; speeds faster than that require an air-breathing ramjet, which compresses high-speed air for combustion, but which typically begins operating at about Mach 4. To bridge the gap, engineers are developing a hybrid engine that can operate in three modes. The aircraft will accelerate to about Mach 3 under turbojet power, switch to ramjet power to take it to about Mach 5, and then switch again to scramjet mode, which uses supersonic air for combustion.

2

SKIN

Aerodynamic friction at speeds exceeding Mach 5 will heat an aircraft's exterior to 2,000 degrees. At that point, conventional steel airframes will melt. So engineers are looking at composites—the same kinds of high-performance carbon, ceramic, and metal mixes used for the noses of intercontinental ballistic missiles and space shuttles. Every joint and seam must be sealed: Any air leak at hypersonic speed, and the in-rushing heat would cause the aircraft to collapse. (That's what doomed the space shuttle Columbia).

3

AIRFRAME

The stresses on a plane shift as it travels through subsonic, supersonic, and hypersonic speeds. For instance, when a jet is accelerating through subsonic flight, the center of lift moves toward the back of the aircraft. But once the craft hits hypersonic speeds, drag on the plane's leading egdes cause the center of lift to move forward again. If the ceter of lift gets too close to the center of gravity it can cause dangerous instability. The plane's shape must tolerate these changes, and more, to keep the craft from tearing apart.

4

PAYLOAD

Lockheed describes the SR-72 as an intelligence, surveillance, reconnaissance, and strike platform, but its exact payload is secret. Most likely, it hasn't yet been invented. Taking spy photos or dropping bombs at Mach 6 will require extraordinary engineering. It will require hundreds of miles to make a turn. It will need powerful guidance computers to line up targets, 80,000 feet below. Also, you can't just open a bomb bay at 4,000 miles per hour. The SR-72 will need new sensors and weapons to operate at such high speeds.

+

HOW RAMJETS WORK

Ramjets forgo the big rotary compressors needed on turbojets and instead rely on their own forward motion to compress air. First, air is scooped into an inlet and compressed as it funnels into a diffuser. The diffuser also slows the air to subsonic speeds for easier combustion. From there, air and fuel are fed into a combustion chamber and ignited. Finally, an exhaust nozzle accelerates the resulting burst of hot, expanding air, producing massive thrust.

BUZELLI

LONG LIVE THE MAMMOTH

WE HAVE THE TOOLS TO BRING BACK EXTINCT SPECIES. HERE'S HOW SCIENTISTS PLAN TO DO IT

BY **BETH SHAPIRO** ILLUSTRATION BY **CHRIS BUZELLI**

THE FIRST USE OF THE WORD "DE-EXTINCTION" WAS, AS FAR AS I CAN TELL, IN SCIENCE FICTION. IN HIS 1979 BOOK *THE SOURCE OF MAGIC*, PIERS ANTHONY DESCRIBES AN EXPLORER WHO SUDDENLY FINDS HIMSELF IN THE PRESENCE OF CATS, WHICH, UNTIL THAT MOMENT, HE had believed to be an extinct species. Anthony writes, "[The explorer] just stood there and stared at this abrupt de-extinction, unable to formulate a durable opinion." I imagine this is precisely how many of us might react to our first encounter with a living version of something we thought was extinct.

ILLUSTRATION BY CHRIS BUZZELLI

The idea that de-extinction may actually be possible—that science could advance to the point where extinction is no longer forever—is both exhilarating and terrifying, even to me. I am a biologist. I teach classes and run a research laboratory at the University of California at Santa Cruz. My lab specializes in a field of biology called ancient DNA. We and other scientists working in this field develop tools to isolate DNA sequences from bones, teeth, hair, seeds, and other tissues of organisms that used to be alive. We then use those sequences to study ancient populations. The DNA we extract from these remains is largely in terrible condition, which is not surprising given that it can be as old as 700,000 years.

During my career, I have studied DNA from an assortment of extinct animals, including dodos, giant bears, steppe bison, North American camels, and saber-toothed cats. By piecing together the DNA sequences that make up these genomes, we can learn nearly everything about an individual animal's evolutionary history: how and when the species to which it belonged first evolved, how the population in which it lived fared as the climate changed during the ice ages, and how the physical appearance and behaviors that defined it were shaped by the environment in which it lived. I am fascinated and often amazed by what we can learn about the past simply by grinding up a piece of bone and extracting DNA from it. Yet, regardless of how excited I feel about our latest results, the most common question about them I receive is, "Does this mean that we can clone a mammoth?"

Always the mammoth.

The problem with this question is that it assumes that, because we can learn the DNA sequence of an extinct species, we can use that sequence to create an identical clone. Unfortunately, this is far from true.

To clone Dolly the sheep in 1996, scientists at the Roslin Institute, which is part of the University of Edinburgh in Scotland, removed a small piece of mammary tissue that contained living cells from an adult ewe. They used the DNA in these cells to create an identical copy of the ewe. This process is called somatic cell nuclear transfer, or, more simply, nuclear transfer. For species that have been extinct for a long time, however—the passenger pigeon, the dodo, the mammoth—cloning by nuclear transfer not a viable option. It requires intact cells. No such cells have ever been found in the remains of extinct species recovered from the frozen tundra.

Degradation of cellular DNA begins immediately after death. Plant and animal cells contain enzymes whose job it is to break down DNA. These enzymes, called nucleases, are found in cells, tears, saliva, sweat, and even on the tips of our fingers. Nucleases are essential while we're alive. They destroy invading pathogens before they can do any damage. They remove damaged DNA so that our cells can fix what's broken. And, after our cells die, they break down the DNA in those dead cells so that our bodies can more efficiently get rid of them. In the lab, we stop nucleases from degrading away the DNA we're trying to isolate, either by dropping a fresh sample into a solution of chemical inhibitors or by subjecting it to rapid freezing. The Arctic is a cold place, but it can't freeze something as large as a woolly mammoth quickly enough to protect its DNA from decay.

Besides nuclear transfer, the other path to creating a living organism is eerily reminiscent of the movie *Jurassic Park*. As is likely to be true in real-life de-extinction projects, *Jurassic Park* scientists were able to recover only parts of the dinosaur genome—in their case, from mosquito blood preserved in amber. When they came across gaps in the dinosaur genome, they used frog DNA to complete the sequence. Unfortunately, they couldn't know beforehand which bits of DNA would help make a dinosaur look and act like a dinosaur and which bits were junk. We can assume these fictional scientists were hoping that the holes they were filling were mostly in the junk-containing regions. But, of course, they were wrong, and some of that frog DNA let the unextinct dinos switch sexes miraculously, leading to disaster and $1 billion in global box-office earnings.

In real-life de-extinction science, the plan is to determine which parts of the genome are important in making the extinct species look and act the way it did. We would then find the corresponding parts of the genome of a close living relative, cut out key sequences, and replace them with versions from the extinct species.

That's easier said than done.

THE OTHER PATH TO CREATING A LIVING ORGANISM IS EERILY REMINISCENT OF THE MOVIE *JURASSIC PARK*.

* * *

The common ancestor of mammoths, Asian elephants, and African elephants lived about six million years ago. This means the mammoth spent many millions of years evolving separately. Some of the hardest parts of the mammoth's genome to assemble will be those that changed in mammoths since they diverged from elephants. For the purposes of de-extinction, these sequences will likely be the most critical to get right.

Fortunately, we don't have to clone a mammoth to resurrect mammoth traits or behaviors. We could, for example, learn the DNA sequence that codes for mammoth-like hairiness and then change the genome of a living elephant to make a hairier one. Obviously, resurrecting a mammoth trait is not the same thing as resurrecting a mammoth, but it is a step in that direction.

Scientists know much more today than they did even a decade ago about how to manipulate cells, sequence the genomes of extinct species, and engineer the genomes of living ones.

A Model Specimen

NOT ALL CLONES REQUIRE DNA. ANCIENT CREATURES CAN BE PROGRAMMED TO ROAM THE EARTH

We may never be able to clone dinosaurs *Jurassic Park*–style: If we did somehow find ancient DNA in a preserved mosquito, it would be far too degraded to use. But new research in the field of robo-paleontology offers a way to bring back ancient creatures as robots.

If fossils show what extinct animals looked like, robots can reveal how they actually moved. For example, we know that our ancestors likely used fins to crawl out of the water some 300 million years ago. But we don't know how these fishy tetrapods, or "fishapods," maneuvered bodies best suited for swimming on land. To find out, Daniel Goldman, a physicist at the Georgia Institute of Technology, modeled a robot after one of the fishapod's modern analogs, the mudskipper. By setting the robot loose on different surfaces and watching it succeed or fail, he is observing how fin-steps may have worked—a clue to how the fishapod evolved.

Another robot could reveal the heavy footsteps of one of the largest animals ever to walk the earth. The 65-ton *Dreadnoughtus* discovered by Drexel University paleontologist Ken Lacovara was exquisitely preserved. So Lacovara scanned all 145 of its bones and 3-D printed the two in its forelimb at one-tenth scale. He fashioned the elbow joint using wires as muscles and a rubber pad for cartilage. Together with a computer simulation of the entire animal, the robotic joint will demystify how *Dreadnoughtus* moved efficiently enough to conserve calories and maintain its giant physique. "The goal is to understand an extinct dinosaur in the way a biologist can understand a raccoon, a tuna fish, or a black bear," says Lacovara. **SHANNON PALUS**

These three technologies pave the way for the most likely de-extinction scenario, or at least the first phase: the creation of a healthy individual.

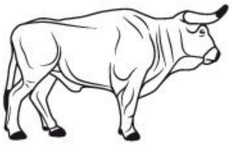
Here's how that might work. First we find a well-preserved bone from which we can sequence the complete genome of an extinct species, such as a woolly mammoth. Then we study that genome, comparing it with those of living relatives. The mammoth's closest living relative is the Asian elephant, so that is where we will start. We identify differences between the elephant's genome and the mammoth's, and we design experiments to tweak the elephant genome, changing a few DNA bases at a time, until it looks more mammoth-like. Then we take a cell that contains one of these new, mammoth-like genomes and allow it to develop into an embryo. Finally, we implant this embryo into a female elephant, and about two years later, that elephant gives birth to a baby mammoth.

Scientists have already sequenced most of the mammoth genome, which was pieced together from fragments of DNA extracted from mammoth bones. Researchers in George Church's lab at Harvard University have also taken the next step. They used a new genome-editing tool to splice the DNA that codes for 14 mammoth characteristics–among them, denser hair, thicker layers of fat, and blood cells that could transport oxygen more efficiently at cold temperatures–into an elephant genome. It is not yet possible to grow these cells into a whole organism, but the Harvard team is working to develop that technology as well. If successful, the embryo, whose genome contains some very tiny portion of mammoth DNA, could eventually develop into a living, breathing animal.

But what would be the end product of this experiment? Is making an elephant whose genome contains a few mammoth parts the same thing as making a mammoth?

Life After Death

SCIENTISTS ARE ATTEMPTING TO RESURRECT A HANDFUL OF EXTINCT SPECIES



AUROCHS

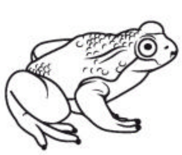
Bos primigenius

WHY: Herbivores like this six-foot-tall wild ox, which went extinct in 1627, could help restore European grasslands.
HOW: Domestic cattle are descended from wild aurochs, and some still contain aurochs-like traits. Through selective breeding, a Dutch organization called the True Nature Foundation plans to concentrate these traits in a single lineage. After many generations, they will have an aurochs-like animal—and will have essentially reverse-engineered domestication.
STATUS: The Dutch team has begun selecting rare cattle breeds for this purpose, including some endangered ones.

BUCARDO

Capra pyrenaica pyrenaica

WHY: A falling tree killed Celia, the last member of this Spanish mountain goat species, in 2000. That sad tale plus the promise of scientific glory amounts to an irresistible challenge.
HOW: A team of French, Spanish, and German scientists injected nuclei from Celia's cells—which had been preserved in liquid nitrogen—into ibex eggs using a technique called somatic cell nuclear transfer. They implanted those eggs into a goat-ibex hybrid.
STATUS: In 2003, a clone was born, but a lung defect caused it to suffocate after just 10 minutes. Researchers are now considering using Celia's remaining cells to try again.



GASTRIC BROODING FROG

Rheobatrachus silus

WHY: The females of this amphibian, discovered just before it disappeared completely in the 1980s, incubate embryos in their stomachs by controlling stomach acid—potentially useful knowledge for treating ulcers in humans.
HOW: After well-preserved tissue samples were discovered in a freezer, the frog became a candidate for somatic cell nuclear transfer. Scientists from Australian universities replaced the nucleus of a barred frog egg with that of the extinct species.
STATUS: The team has coaxed the cells into dividing into an early-stage embryo in a petri dish. Getting it to turn into a tadpole is the next step.

PASSENGER PIGEON

Ectopistes migratorius

WHY: Despite flocks millions strong, hunters extinguished the passenger pigeon just over 100 years ago. Reversing that feat would be an honorable (if belated) gesture.
HOW: Bird eggs begin to develop into embryos before scientists can access the nucleus. So U.S. researchers plan to inject band-tailed pigeon embryos with primordial germ cells, edited to be as passenger pigeon–like as possible. Germ cells develop into sperm or eggs, which will produce a passenger-like pigeon in the next generation.
STATUS: Scientists have so far sequenced DNA from 43 museum specimens, including some that are nearly 4,000 years old, in order to map the pigeon's genome.

HEATH HEN

Tympanuchus cupido cupido

WHY: These birds, once a fixture in New England ecosystems (and a staple on local menus), were hunted to extinction in the late 1800s. Genome editing could succeed where a heath hen reserve, established in 1908 on Martha's Vineyard, Massachusetts, failed.
HOW: Scientists must use the genome of a related species, the greater prairie chicken, as a scaffold for mapping the fragments of DNA found in old heath hen specimens.
STATUS: A team of U.S. scientists assembled the genome of a prairie chicken and is sequencing nine other closely related birds, including several heath hens.

SHANNON PALUS

ILLUSTRATIONS BY TODD DETWILER

After all, an animal is more than a simple string of As, Cs, Gs, and Ts—the letters that represent the nucleotide bases that make up DNA. Today, we don't fully understand the complexities of how we get from simply stringing those letters together in the correct order to making an organism that looks and acts like the real thing. That will involve much more than merely finding a well-preserved bone and using it to sequence a genome.

* * *

When I imagine a successful de-extinction, I don't imagine an Asian elephant giving birth to a slightly hairier elephant under the close scrutiny of veterinarians and excited scientists. I don't imagine the spectacle of this exotic creature in a zoo enclosure, on display for the gawking eyes of children who'd prefer to see a *T. rex* or *Archaeopteryx* anyway.

What I do imagine is the perfect arctic scene, where mammoth (or mammoth-like) families graze the steppe tundra, sharing the frozen landscape with herds of caribou, horses, and reindeer—a landscape in which mammoths are free to roam, rut, and reproduce without the need for human intervention and without fear of re-extinction. This constitutes the second phase of de-extinction, which builds on the successful creation of an individual to produce and eventually release an entire population into the wild. In my mind, de-extinction cannot be successful without this second phase.

That idyllic arctic scene might be in our future. But first, science has some catching up to do with the movies. Though we have sequenced nearly the entire mammoth genome, that work is not yet complete. We are also a long way from understanding precisely which bits of that sequence are important to making a mammoth look and act like one. This makes it hard to know where to begin and nearly impossible to guess how much work might be in store for us.

Another problem is that some major differences between species or individuals, such as when a particular gene is turned on during development, are inherited epigenetically. That means that the instructions for these differences are not coded into the DNA but are determined by the environment in which the animal lives. What if that environment is a captive breeding facility? Baby mammoths, like baby elephants, ate their mother's feces to establish a microbial community capable of breaking down the food they consumed. Will it be necessary to reconstruct mammoth gut microbes? A baby mammoth will eventually need a large, open space where it can roam freely but also be safe from poaching and other dangers. This will likely require a new form of international cooperation and coordination.

My goal is not to argue that de-extinction will not and should never happen. In fact, I'm nearly certain that someone will claim to have achieved de-extinction within the next several years. I will argue, however, for a high standard by which to accept this claim. Should de-extinction be declared a success if a single mammoth gene is inserted into a developing elephant embryo and that developing elephant survives to become an adult? Purists may say no, but I would want to know how inserting that mammoth DNA changed the elephant. What if a somewhat hirsute elephant is born with a cold-temperature tolerance exceeding that of every living elephant? And what if that elephant not only looks more like a mammoth but is also capable of reproducing and sustaining a population where mammoths once lived?

While others will undoubtedly have different thresholds for declaring de-extinction a success, I argue that this—the birth of an animal that is capable, thanks to resurrected mammoth DNA, of living where a mammoth once lived and acting, within that environment, like a mammoth would have acted—is a successful de-extinction, even if the genome of this animal is decidedly more elephant-like.

DE-EXTINCTION IS A PROCESS THAT ALLOWS US TO CREATE A FUTURE THAT IS BETTER THAN TODAY.

De-extinction is a process that allows us to actively create a future that is better than today, not just one that is less bad than we anticipate. It is not important that we cannot bring back a creature that is 100 percent mammoth or 100 percent passenger pigeon. What matters is that—today—we can tweak an elephant cell so that it expresses a mammoth gene. In a few years, those mammoth genes may be making proteins in living elephants, and the elephants made up of those cells might, as a consequence, no longer be isolated to pockets of declining habitat in Africa and Asia. Instead, they will be free to wander the open spaces of Siberia, Alaska, and Northern Europe, restoring to these places all the benefits of a large dynamic herbivore that have been missing for around 8,000 years. Large herbivores knock down trees and trample bushes, for example, and transport seeds and nutrients over long distances. By removing snow, mammoths—or rather, cold-tolerant Asian elephants—may also expose the permafrost to the bitter cold of Siberian winters. This would lower the temperature of the soil and slow the release of greenhouse gases trapped within it.

De-extinction is a markedly different approach to planning for and coping with future environmental change than any other strategy that we, as a society, have devised. It will reframe our possibilities.

This story was adapted from Beth Shapiro's book How to Clone a Mammoth: The Science of De-extinction, *published in May.*

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the NEW FACES of ENERGY

There is a quiet revolution going on in energy. Domestic oil and gas production are up, and renewables are coming into their own. In the next five years, the way we make, store, and deliver power will drastically change. These 12 scientists and entrepreneurs are at the forefront of that transformation.

PHOTOGRAPHS BY
MARIUS BUGGE

1&2/

Leslie Dewan & Mark Massie

REVIVE THE NUCLEAR DREAM

Pictured on previous pages

ONE DAY IN 2009, Leslie Dewan and Mark Massie were rummaging through old articles in an MIT library. There, they found two things the nuclear industry had abandoned a half century before. One was a sense of urgency: The first fast-neutron reactor had gone from scribbles on a napkin, in 1945, to a working prototype in only 18 months. The other was something called a molten salt reactor.

In the 1960s, scientists had operated one at Oak Ridge National Laboratory in Tennessee. But then funding dried up, light-water reactors became the industry standard, and molten salt was all but forgotten. That seemed absurd to Dewan and Massey. Molten salt reactors, they learned, are safer than what's used today. They burn liquid uranium fuel, rather than solid fuel, which reduces the chance of a meltdown. As part of a generation of young nuclear scientists motivated by climate change, and willing to take a fresh look at nuclear power, Dewan and Massey wondered why the world wasn't using this. They knew that to beat out cheap coal and natural gas, new reactors needed to be safer and more efficient. So they dusted off the Oak Ridge design and got to work.

Today, their start-up, Transatomic Power, is poised to build a new, even better molten salt reactor. Their reactor will burn up to 96 percent of its fuel, compared with only four percent used by light-water reactors, and generate 75 times the electricity per ton of uranium. It's virtually accident-proof and can run on the spent fuel of other reactors. With nearly 80,000 tons of radioactive waste in the U.S. (and with 2,000 tons added every year), it could turn something toxic into something useful. "That's what sets Leslie Dewan and Mark Massie apart," says Richard Lester, head of the nuclear science and engineering department at MIT. "Their design addresses radioactive waste, which is huge."

So far, Transatomic has obtained $6 million in funding, including $2 million from venture capital firm Founders Fund (backers of Spotify, Airbnb, and SpaceX). Dewan and Massie have used some of this seed money to set up a lab in Cambridge, Massachusetts, where, for the next three years, they will test materials for their future reactor under the extreme conditions created by nuclear fission. But their road to an actual reactor will be a very long one.

Consider America's relationship with nuclear power. During the Cold War, the U.S. wanted to build a commercial nuclear power industry before the Russians. The U.S. Navy already used light-water nuclear power on its submarines, providing an easy blueprint to expand upon. The early and technically expedient decision to commercialize light-water reactors, "locked the U.S., and the rest of the world, into one type of technology," Dewan says.

All 99 U.S. commercial reactors in use today are light-water reactors. That uniformity is not a problem until something goes wrong—and then the entire nuclear industry gets tarred with the same brush. The meltdowns at Three Mile Island and Chernobyl turned an entire generation away from nuclear power. The meltdown at the Fukushima Daachi plant in 2011 deterred another, despite the fact that nuclear is easily scalable, carbon-free, base-load power. "When nuclear fails, it fails spectacularly," Massie says. "And it gets a lot of coverage."

When I visit their offices in Cambridge, Dewan and Massie clutter up a whiteboard to show just how safe and efficient their reactor will be. In light-water reactors, fuel rods packed with uranium pellets are submerged in water, which slows neutrons to a speed that induces fission in the uranium and heats the rods. The hot water then powers a steam turbine that generates electricity. The system works well, except for two problems.

The first is that fission product poisons, like krypton and xenon, accumulate in the rods. These gases consume neutrons, which ultimately stops the fission reaction. Every four years or so the rods need replacing, even though 96 percent of their energy remains untapped, rendering them highly radioactive waste products that have to be stored in a secure location forever. The other problem is the reactor's constant need for electric power to pump cold water over the core, which holds the fuel rods. This water prevents it from overheating. Lose power, like at Fukushima, and the core melts down.

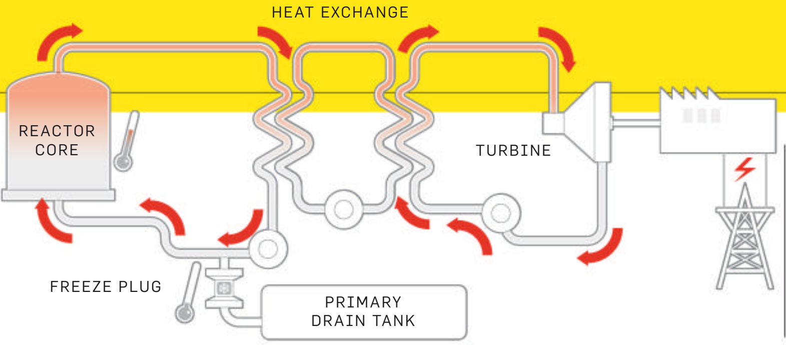
In molten salt reactors, uranium salt serves as the fuel. When heated above 500°C, the fuel salt changes from a solid to liquid state. It flows past zirconium hydride, which slows its neutrons and induces fission, generating heat. Because there are no rods to trap krypton and xenon, they are continuously off-gassed. "You basically simmer the reactor like a Crock-Pot for decades," Dewan says. "That's how we achieve a 96 percent burn rate. We're able to

TRANSATOMIC POWER IS POISED TO BUILD AN EVEN BETTER MOLTEN SALT REACTOR. IT'S VIRTUALLY ACCIDENT-PROOF AND CAN RUN ON THE SPENT FUEL OF OTHER REACTORS.

HOW IT WORKS

1.
Rather than use solid fuel, a molten salt reactor heats uranium salt to more than 500°C, liquefying it.

2.
The liquid fuel flows past a moderator that slows down neutrons and induces fission, generating heat for steam turbines.



3.
If a reactor loses power, a freeze plug melts, draining the radioactive fuel into a tank where it cools to a solid.

leave the uranium in and constantly remove the poisons that would otherwise shut it down." The fuel salt flows through a loop with a drain that's blocked by a freeze plug, a chunk of electrically cooled frozen salt. If the reactor loses electricity, the plug melts, and the fuel drains into a tank where it cools and solidifies.

While the nuclear physics of molten salt reactors were proved at Oak Ridge 50 years ago, Dewan and Massie need to rigorously test the reactor's materials. Down the street from their Cambridge offices, Dewan shows me a lab where they'll be exposing metals and ceramics—components that could be used in the reactor's pipes, pumps, and valves—to salt and extreme heat using a furnace the size of a refrigerator. Their next step will be to design and build a 20-megawatt demonstration reactor that they hope to have running by 2020. Their ultimate goal is a 520-megawatt commercial reactor, which they say can be built for $1.7 billion—half the cost of a light-water reactor.

Despite the favorable economics, the U.S. Nuclear Regulatory Commission is not focused on licensing advanced reactors. "There's no regulatory framework that allows a developer to say, 'This is what we need to get approval,'" says Lester. That, in turn, deters investment. "Investors want to see a regulatory pathway," Lester says. So companies like Bill Gates's TerraPower, which has developed a next-generation traveling-wave nuclear reactor, are looking to build abroad. Massive energy needs and pollution problems have driven China to investigate many types of reactors—molten salt, sodium-cooled fast reactors, and high-temperature reactors. China may commission multiple models, since it plans to build 45 reactors over the next decade.

To Dewan, sending their technology to China would be a missed opportunity. If the U.S. wants to lead the world in clean, safe nuclear energy again, she says, it urgently needs to broaden regulations. But there's resistance from the coal and natural gas industries, which see nuclear energy as a bottom-line threat, and from some environmental groups that argue nuclear will always pose risks. But Dewan is undeterred. She doesn't want to build a molten salt reactor in China. She wants to keep Transatomic's operations in the U.S., where the promise of nuclear energy was born. "It's American technology," she says. "It's American engineers. We want this country to have the benefits of it first." **PAUL KVINTA**

3 / Alejandro Rios

GROWS FUEL IN A DESERT

Commercial jets burn 71 billion gallons of fuel annually, most of it refined from crude oil. Biofuels promise a cleaner alternative, but they typically consume too many other resources, such as fresh water and arable land, or are simply not economically viable. Alejandro Rios, director of sustainable bioenergy at Abu Dhabi's Masdar Institute, believes he has found a way around both problems: halophytes, plants that grow in the desert, thrive on seawater, and produce oil-rich seeds.

With support from aviation heavyweights, including Boeing, Rios has begun a nearly five-acre pilot project in Abu Dhabi. He will irrigate his first crop of halophytes with nutrient-rich recycled seawater from local fishponds. The plants should be ready for harvest in eight months. Then oil will be extracted and refined. Rios has high hopes that the project, when scaled, up, will yield fuel at a price competitive with fossil fuels. "If we're able to produce jet fuel using salt water on arid land," says Rios, "that's a game changer." Assuming all goes well, he hopes to enter the market within five years.
OSHA GRAY DAVISON

4 / Larry Baxter

FREEZES CARBON INTO SNOWFLAKES

There's little debate that capturing carbon dioxide from coal-fired power plants is important. The problem is that it's an energy-intensive process: The typical carbon-capture system can consume nearly 30 percent of a plant's power output, mainly by heating solvents that scrub CO_2 from chimneys only to cool them down again. Chemical engineer Larry Baxter of Brigham Young University is developing a more efficient way to remove the greenhouse gas: by freezing it into snowflakes. "It makes capture realistic and affordable," he says.

Baxter's start-up, Sustainable Energy Solutions, uses a cryogenic carbon-capture system to chill the emissions stream. When the carbon dioxide turns into an icy solid, it separates from other gases. "You get this blizzard of dry-ice flakes," he says. The CO_2 is then pressurized and melted into a liquid that can be safely stored in underground aquifers. In pilot studies, the system captured 99 percent of the carbon dioxide from emissions, while costing a quarter of what conventional methods do. It also scrubs other noxious chemicals from emissions, including mercury. **MARY BETH GRIGGS**

ILLUSTRATION BY TREVOR JOHNSTON

5/ Gregg Semler

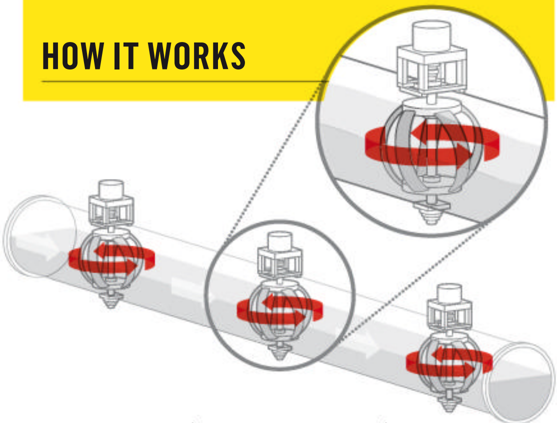
TURNS TINY TURBINES INTO MIGHTY GENERATORS

Pictured at left

Twenty feet below a street in Portland, Oregon, Susan Priddy stands amid 50 feet of city-owned water pipes. Inside these pipes sit four keg-size turbines that look like giant egg beaters—only they churn out hydroelectric power. "We're capturing energy that would otherwise be lost," says Priddy, director of operations for Lucid Energy, a Portland start-up.

In January, Lucid became the first company in the U.S. to install a commercial micro-hydro energy system, flipping the switch on 1,100 megawatts of renewable energy annually. "I'm attracted to solutions to big problems," says Gregg Semler, Lucid's CEO. "Things that nobody has done before." Semler had worked as a clean-energy entrepreneur for 10 years when he was recruited to helm Lucid in 2011. Under his guidance, the Portland project will generate enough electricity to power 150 homes per year. Over the next two decades, that adds up to $2 million worth of energy sold to the local utility. The implications are even more significant.

HOW IT WORKS



1.
Inside Portland's 42-inch-wide municipal water pipelines, Lucid Energy installed four five-bladed turbines roughly every 12 feet.

2.
As the water moves from high to low elevation, pressure builds in the pipe. The turbines convert that pressure into electricity via a generator on top of the pipes.

3.
Sensors installed inside the pipe detect changes in water pressure, help predict a burst pipe, and monitor for contaminants in the drinking water.

ILLUSTRATION BY TREVOR JOHNSTON

Torrents of water rush beneath cities all over the world; in Portland's case, they move at an average rate of 39,000 gallons per minute. Lucid harnesses that energy with a system that's striking in its simplicity. The only technology inside the water pipes are five-bladed spherical turbines, 42 inches in diameter, made of stainless steel and composite fiber. Most of the other parts—seals, bearings, grid connections—sit outside them. "The whole system is designed so water delivery is never disrupted," Priddy says. Turbines installed in water pipes also come with no environmental costs. It's a sharp contrast to hydroelectric dams, which can kill fish and harm other wildlife.

Lucid's system works in gravity-fed pipes, which makes them a good fit for western and northeastern states, where water rushes downhill into showers and sprinklers. Sensors in the pipes provide data on water pressure and quality, which can forewarn of burst pipes or water contamination. Still, getting cities to use the system can be a tough sell.

Water managers tend to be risk-averse when it comes to new technology: Their priority is to deliver clean, safe drinking water, not to generate power. But a pilot project in Riverside, California, in 2012 demonstrated the safety and potential of the system Lucid designed. As a result, the company's turbines are certified for use in pipes that carry municipal drinking water, as well as industrial, irrigation, and wastewater. Utilities also have tight budgets, which is why Lucid brought in an investment outfit, Harbourton Alternative Energy, to pay for the $1 million installation cost in Portland. The city, the Portland Water Bureau, and investors will share revenue generated by the turbines for the next 20 years. Then the utility can own them outright. Since water pipes can last 50 years or more, additional revenue could be huge. "It could provide a new form of income for water facilities," Semler says.

They will need it. An estimated 240,000 water mains break each year. The nation's pipes are in such bad shape, says the Environmental Protection Agency, that it will take $650 billion to repair them all.

Since installing its Portland project, Lucid has heard from water suppliers all over the world, including China, Brazil, Canada, and Korea. "Local, cleaner sources of energy," Semler says, "really resonate with people." **VIRGINIA GEWIN**

6/ Pablo Ruiz

PREVENTS BOTTLENECKS IN THE ELECTRICITY GRID

Rush hour isn't just a traffic problem. Power lines, too, back up at peak times. The result: high electric bills and blackouts. That's why a team led by Pablo Ruiz, an engineer at Boston University, designed software to detect grid congestion and redirect power to lesser-used transmission lines. It could save U.S. consumers more than $1 billion a year in peak-hour costs.

The process, known as grid smoothing, also makes room for renewable energy sources, which tend to enter the power grid in spurts. Smoothing ensures that the system pulls heavily from turbines on windy days or draws on conventional sources when the sun is too weak to feed solar arrays. A higher percentage of energy from renewable sources generally lowers consumer costs. Even better, utilities don't need hardware upgrades to see the benefits. "All they have to do is install the new program," Ruiz says. **MARY BETH GRIGGS**

7/

Susan Kennedy

STOPS BLACKOUTS BY STORING ENERGY

Susan Kennedy pulls her black BMW into a winery in California's Sonoma County. She steps out, strides past the stainless-steel fermenting vats, and stops at a concrete pad. There, contractors are installing what appears to be a large metal cabinet—the kind that might store museum specimens. In fact, it's a 200-kilowatt lithium-ion battery made by the electric-car company Tesla. Its job is to charge from on-site solar panels during the day and from the grid at night. The winery will draw on this battery power when electric rates spike.

"What I like is the modularity," Kennedy says, eyeing the eight-foot cube. That isn't a casual observation; Kennedy is shopping. Her San Francisco start-up, Advanced Microgrid Solutions (AMS), needs batteries to fit into parking lots where space is at a premium. That's how the company plans to revolutionize the electricity grid. Kennedy glances up. "You're looking at the future," she says.

Fast-moving and sinewy, Kennedy has spent more than 15 years in the crucible of California energy policy. She has a reputation for speaking bluntly and thinking big. AMS doesn't just plan to power individual buildings; it intends to turn office complexes and industrial facilities into tools that make the grid more efficient and resilient.

By 2018, AMS will have outfitted 75 to 100 buildings with stationary energy systems. Then on summer days, when everyone is running their pool pumps and air conditioners, these so-called hybrid-electric buildings could shift seamlessly to battery power at the utility's request. Typically, a utility copes with high demand by bringing an additional power plant online; instead AMS will reduce the utility's load by up to 50 megawatts—enough to power 20,000 homes. "Susan and her team are unlocking the notion of using customer-side resources as capacity," says Julie Blunden, an energy consultant who chairs the governing body for the public-private consortium Cal-Charge. "That is an absolutely tectonic shift for utilities."

Kennedy felt pressure building along that fault line as far back as 1999. She had just been named cabinet secretary for California's then-governor, Gray Davis, when she learned that power shortages and high wholesale prices were pushing the state toward an energy crisis. A colleague warned that Californians might soon face brownouts and rolling blackouts.

"Brownouts? That's third-world," she remembers thinking. "It was so anathema to everything we understood about our electricity grid that we couldn't even grok it." As the governor's point person for policy issues, Kennedy was charged with keeping the lights on. She did this, in part, with an emergency conservation program that asked corporate and residential customers to scale back their usage. Californians lost power at times in 2000 and 2001, but researchers at Lawrence Berkeley National Laboratory estimate that the belt-tightening prevented 50 to 160 hours of blackouts.

The problem with such a strategy is that it demands sacrifice, such as reducing air conditioning or shutting down production lines. True grid stability would require a painless way to unplug. That seemed like an impossibility during the next decade of Kennedy's career—first as cabinet secretary, then as a member of the California Public Utilities Commission, and later as chief of staff for Davis's successor, Arnold Schwarzenegger. Then, batteries matured. "Because of the electric-vehicle market and the cellular market, lithium-ion is now a very advanced technology," she says. "It is compact, dense, scalable, and the price point is coming down."

Kennedy pondered how to take maximum advantage. "I was trying to think: How do I use this technology and make it into something grid-scale?" She began talking with Jackalyne Pfannenstiel, a former assistant Navy secretary in charge of energy programs. The two had worked together when both held state energy-policy jobs. "Susan's project just rang my bell," says Pfannenstiel, who started her career in the 1970s by studying whether utility customers would shift their consumption from peak to off-peak hours. In 2012, Kennedy and Pfannenstiel founded AMS.

At the same time, California officials were seeing energy storage as critical to achieving a major goal: the transition away from fossil fuels. The year before, state lawmakers had mandated that utilities generate one-third of their energy from renewable sources like solar and wind by 2020. (Governor Jerry Brown wants the figure to hit 50 percent by 2030.) But these resources are not available 24/7. The sun goes down. The wind stops blowing. "We have to match supply to demand all the time," says Carla Peterman, a public utilities commissioner. "The idea of storage is very natural: We have our closets. We have our pantries. We have our fat cells."

Furthermore, although the state was soon awash in renewable energy, its antiquated transmission and distribution systems lacked the capacity to move that energy to where it was needed most. Instead of extensive new power lines, Kennedy and others believed, the solution would come in the form of small, flexible power sources near

ON SUMMER DAYS WHEN EVERYONE IS RUNNING THEIR POOL PUMPS AND AIR CONDITIONERS, HYBRID-ELECTRIC BUILDINGS COULD SHIFT SEAMLESSLY TO BATTERY POWER AT THE UTILITY'S REQUEST.

where customers lived. Southern California Edison (SCE) requested proposals to replace 2,221 megawatts of lost capacity. By November 2014, AMS had landed a contract.

The company's first project, a cluster of about 22 office buildings in Irvine, California, will come online with batteries totaling 10 megawatts by mid-2017. The second phase, in West Los Angeles, will be ready to store 40 megawatts by the following year. SCE will pay AMS, which in turn will provide the buildings with services like energy-management software and energy audits. AMS also plans to supply more battery capacity than SCE needs. Building managers would be able to draw on the extra kilowatts during peak hours to avoid the highest rates. Kennedy estimates that this will reduce electricity costs by 10 to 20 percent.

These "virtual power plants," to Kennedy, make up the grid of the future: nimble, decentralized, and less reliant on fossil fuels. "Our entire grid was built as a dumb system, where central power stations pushed out electrons and consumers just burned them," she says. "Storage is the alchemy of turning the customers' load into something they can control." **BARRY YEOMAN**

8/

Eric Loth

THINKS LIKE THE WIND

The bigger the blades on a wind turbine, the more megawatts the machine can produce. So it's no wonder the typical rotor diameter grew nearly 115 feet from 1995 to 2012, increasing average capacity from .75 megawatts to 2.5 megawatts. But at some point, rotors get so big they cost more to build than the value of the energy they can produce. Pretty soon, "we're going to run into a wall," says Eric Loth, an engineer at the University of Virginia. Inspired by a palm tree's ability to bend in strong winds, Loth designed the Morphing Downwind-Aligned Rotor (MoDaR). Its hinged blades rotate downwind to capture energy efficiently. The blades are also lightweight, so they could be as long as 780 feet, which could increase output to 50 megawatts. Something this large likely won't hit the commercial market before 2025, but that's not a problem for Loth: "This concept isn't necessary for today's smaller turbines," he says. "We're working on the future." **OSHA GRAY DAVIDSON**

HOW IT WORKS

1.
The MoDaR attaches to the downwind side of the tower. Blades can bend on hinges to adjust for wind conditions without striking the tower.

2.
A downwind rotor has one big disadvantage: Wind forced around the tower causes turbulence, stressing the system and fatiguing parts. MoDaR's fix is an aerodynamic fairing for the tower.

3.
During storms, the blades can be stowed in a horizontal position to avoid damage.

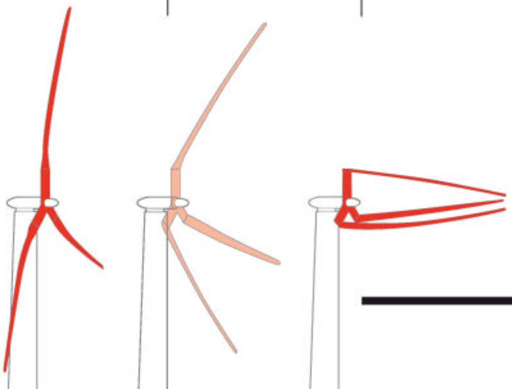


ILLUSTRATION BY TREVOR JOHNSTON

9/

Chris Hagen

GASSES UP AT HOME

Pictured at left

What if you could turn your house into a personal gas station (minus the dirty bathrooms)? Chris Hagen, a mechanical engineer at Oregon State University Cascades, plans to make that possible. He has developed technology to convert as many as 67 million homes into spots to fuel a car.

Although there are only 818 public compressed natural-gas (CNG) stations in the U.S., many homes already have low-pressure natural-gas lines for heat and cooking. Hagen's company, Onboard Dynamics, can retrofit existing vehicle engines to act as natural-gas compressors, turning one cylinder into a dual-function compression-combustion chamber. The result will be home fueling for as little as $1 per gasoline gallon equivalent, he says. Hagen is pitching the idea first to truck operators, such as municipal road crews. "But the big win will be the residential consumer market," he says. There's another upside. Natural gas burns much cleaner than gasoline, so widespread adoption would reduce carbon dioxide emissions significantly. **VIRGINIA GEWIN**

10/

Michael Aziz

MAKES A BATTERY FROM RHUBARB (SORT OF)

The next step for renewable energy is to figure out how to store all the power we create. Harvard researchers have used a molecule nearly identical to one in rhubarb to make a battery that can store more energy—for less money—than solid-state and traditional flow batteries. "We have something that could change the way we deal with electricity," says Harvard engineer Michael Aziz. By 2017, they hope to release a commercial version big enough to hold a day's worth of energy from a typical three-kilowatt home rooftop solar array.

Many existing flow batteries use expensive rare earth metals like vanadium. This new battery is modeled on photosynthesis and uses quinones, small molecules that store energy in plants and animals. They cause a beautiful color change from yellow to red-brown during charging, and are cheap and naturally abundant. Aziz hopes one day to store electricity from solar farms—without depending on scarce, costly materials. **OSHA GRAY DAVIDSON**

11 /

Melinda Sims

PULLS MORE POWER FROM LANDFILLS

Landfills are a potent source of methane, and so companies often drill wells to siphon it as fuel. But managing those wells can be tricky. It requires manually adjusting a vacuum to gather gas from each wellhead. If oxygen enters the well, it can damage the methane-forming bacteria, which means the process needs constant monitoring. In 2011, while a Ph.D. student at MIT, Melinda Sims realized there had to be a more efficient method.

With Andy Campanella, Sims formed a company, Loci Controls, that targets the nation's 645 energy-producing landfills. The company created algorithms that adjust vacuum pressure at individual wells. Their system remotely monitors dozens of wells in real time. The initial results are impressive: One test site showed a 25 percent increase in energy production. Loci's monitoring is also wireless, solar-powered, and user-friendly. "I check on the system on my cellphone," says Sims. **MARY BETH GRIGGS**

12 /

Michael Murray

TRANSFORMS PLASTIC INTO FUEL

Pictured at right

At a factory in Almeria, on the southern coast of Spain, Michael Murray, the CEO of the technology company Cynar, makes an impressive demonstration. A video on Cynar's website shows him filling a glass bottle with a soup distilled from plastic, then marching outside. In a sport coat and rubber gloves, he pours it into the gas tank of a Toyota Land Cruiser. Then he cranks the ignition and drives off.

This isn't just a trick; it's a business plan. Murray intends to convert millions of tons of plastic waste into a synthetic fuel. The factory, which licenses his technology, opened late last year and is already digesting just under one ton of plastic an hour. That translates into 3,693 gallons of diesel a day, enough to fill 230 midsize cars. "I watch this crap going in, smelly, stinky stuff, and get out usable fuel," Murray says.

The chemical process Cynar has mastered is called pyrolysis. It essentially returns plastic to its original state: oil. First, the plastic must be cleaned, shredded, and heated in the absence of oxygen. Instead of burning, it melts to the consistency of chewing gum, and then vaporizes into a hydrocarbon cloud. When the cloud cools, the vapor condenses into a liquid that can be refined to diesel, kerosene, or light oil and used with any car or generator.

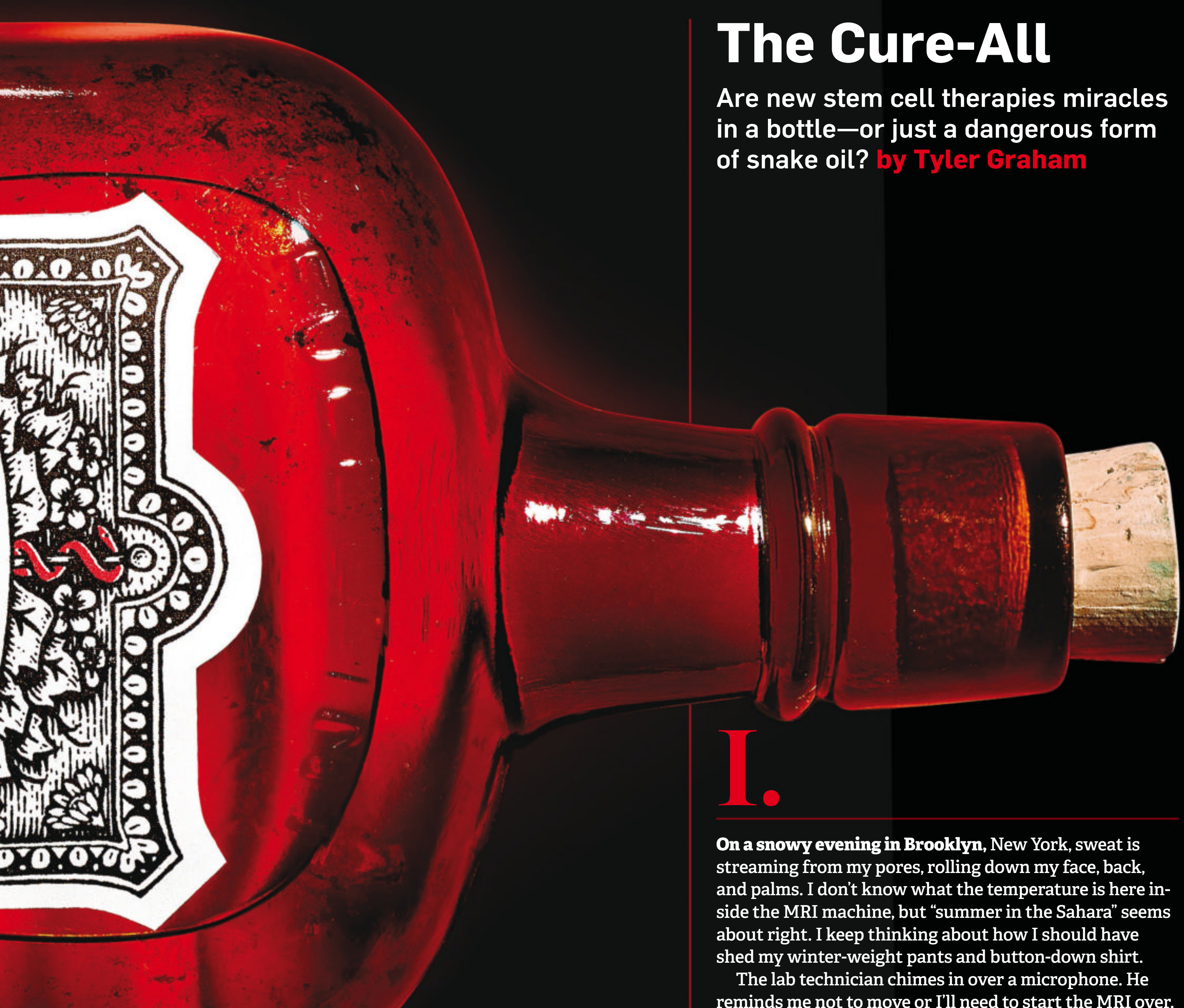
But Cynar's fuel is much cleaner than its conventional counterparts. It produces 20 percent less tailpipe emissions than fossil fuel sold at the pump, according to an analysis by the University of Dublin. And it has the advantage of giving multiple forms of discarded plastic—including grocery bags, polystyrene trays, and even patio furniture—a second life.

Murray has bet nearly $20 million and the past 11 years on his plastic fuel. But to hear him tell it, his hard work is just making amends for the excesses of his youth. He grew up in Dublin with a speed-racing habit: cars, boats, planes—"anything that's got an engine, I raced it," he recalls. After years as a gas hog, his lightbulb moment came when he was throwing away a printer cartridge. There has to be another use for items like these, he thought. A seasoned entrepreneur, Murray decided to try to commercialize pyrolysis.

While pyrolysis isn't new, only recently have technological advances made it scalable, affordable, and profitable. Cynar's diesel costs only $1.75 per gallon to produce. The price of oil, however, has been dropping fast. At press time, it was $56 per barrel and sliding south, right into potential profits. But Murray takes the long view: He wants to bring his technology to developing nations, places with huge landfills and big energy deficits. He is in talks to build a plant in East Africa and also has his eye on the small island nations in the Pacific that he has sailed around. "Some countries have so much plastic trash, but import oil," says Murray. "Imagine if they had a way to get energy from their plastic waste!" **LUBA OSTASHEVSKY** P/S

"SOME COUNTRIES HAVE SO MUCH PLASTIC TRASH, BUT IMPORT OIL," SAYS MURRAY. "IMAGINE IF THEY HAD A WAY TO GET ENERGY FROM THEIR WASTE!"

STEM CELLS
Vanishes
CHRONIC PAIN
INDICATIONS
HERNIATED DISKS, ARTHRITIS, DIABETES, HAIR LOSS, MULTIPLE SCLEROSIS, BLINDNESS, DEAFNESS, KNEE AND HIP PAIN
ALL MANNER OF INFLAMMATION



The Cure-All

Are new stem cell therapies miracles in a bottle—or just a dangerous form of snake oil? **by Tyler Graham**

PHOTOGRAPHS BY
SAM KAPLAN
TYPOGRAPHY BY
NATHAN YODER

I.

On a snowy evening in Brooklyn, New York, sweat is streaming from my pores, rolling down my face, back, and palms. I don't know what the temperature is here inside the MRI machine, but "summer in the Sahara" seems about right. I keep thinking about how I should have shed my winter-weight pants and button-down shirt.

The lab technician chimes in over a microphone. He reminds me not to move or I'll need to start the MRI over. Considering I've been here for 45 minutes, that doesn't sound appealing. My eyes sting, and sweat has pooled in weird places. I imagine this is what Chinese water torture feels like. Add to that, I have a gadolinium contrast agent coursing through my body. The substance is supposed to highlight areas of inflammation, but it can also make you feel like you're itching from within.

Struggling to remain still, I try to focus on why I am here. For seven years, I've wrestled with back pain, a grindingly persistent condition that emanates from beneath my left shoulder blade. To fix it, I have tried nearly everything—physical therapy, exercise regimes, a standing desk, a chiropractor, a Myopractor, acupuncture.

→

Nothing worked. The pain could be dull and nagging or acute and raging. But it was always there, no matter if I was at work, at the beach, or trying to fall asleep. I had to do something drastic. This MRI is the first step. The next will take me to the very fringes of medicine.

II.

A week after my scan, Mark Berman calls from his office in Beverly Hills. Berman is not an orthopedic surgeon. He's a cosmetic surgeon, a nip-and-tuck guy who, like so many others, established his practice at the center of the plastic surgery universe. Business is going so well, what with the usual face-lifts, breast augmentations, and rhinoplasties, that he maintains a second office in Palm Springs.

On the phone, Berman is chatty and affable. He announces that I have four herniated disks but none of them are near the source of my pain. In fact, he says, the MRI turned up nothing near my left shoulder blade. He can probably sense my disappointment—another dead end in a seven-year string of them—so he quickly adds, "This isn't unusual. What we find a lot of the time is that chronic inflammation doesn't get picked up because it's been there so long. But you're still a candidate."

By "candidate," Berman means a potential subject of an unproven surgical procedure, one without any approval from the U.S. Food and Drug Administration (FDA) or extensive scientific support. The treatment uses stem cells—undifferentiated cells that can develop into specialized tissues. In Berman's procedure, the stem cells will come from my own fat. He claims that by circulating them through my body intravenously, they will locate sites of inflammation—whether herniated disks or torn ligaments or arthritis—and repair them. The scientific backing is shaky. There is little quantifiable evidence to defend his claim, which he freely admits. But then he points to his track record. He says he has successfully treated more than a thousand patients, and he happily gives me names and phone numbers.

One is Lamon Brewster, a former heavyweight boxing champion. In 2010, Brewster went up against the Finnish boxer Robert Helenius, a.k.a. the Nordic Nightmare. The two were pretty well matched, but Helenius had the reach. At 6'6" he towered over 6'2" Brewster, and in the eighth round, he landed a series of devastating hooks to Brewster's face. Less than a minute later, the referee called the fight. A few days after that, Brewster learned that his cornea and iris were severely damaged. Within a few months, he lost all sight in his left eye.

The damage, he was told, was irreversible. Then he heard about Berman's therapy. With nothing to lose, he gave it a shot. Months after he received stem cell injections, his vision started to return. "It's getting better each day," he says when I call. He also claims the benefits extend to other parts of his body: "I had boxed a long time and suffered chronic pain. But I didn't realize I had all these issues until they started to go away after my treatment."

"NO ONE HAS PROVED THEY'RE SAFE OR EFFECTIVE.

PEOPLE ARE PAYING A LOT

FOR THESE TREATMENTS WITH NO ASSURANCES."

To someone beset with chronic back pain, the whole thing sounds too good to be true. I've been down the alternative-therapy road before. And I am well aware that many people view clinics like Berman's as potentially dangerous sham operations that promise the impossible. But chronic pain can make even the most rational person irrational. As soon as I get off the phone with Berman, I book my ticket to California.

III.

Scientists have known of stem cells since the 1950s, but the field of regenerative medicine has only really taken hold in the past 15 years or so. In that time, researchers have managed to figure out some of the basics: Stem cells appear to serve two purposes—as a foundation for all tissue in a growing embryo and as a means of repair and replacement in mature tissue. Broadly, they come in two varieties: embryonic (found only in embryos) and adult (which live throughout the body). Embryonic stem cells can differentiate into all 220 tissues in the human body. Adult stem cells typically differentiate into their tissue of origin. For example, those in bone marrow tend to grow into red blood cells, white blood cells, or platelets but not nerve cells. In 2006, researchers found a way to turn adult stem cells into embryonic ones (called induced pluripotent stem cells), but the work is new and the implications still unclear.

Berman's procedure relies on adult stem cells. He collects a small amount of a patient's fat, adds enzymes to digest away the scaffolding that holds the cells in place, and then uses a centrifuge to separate the components. What he collects is called a stromal vascular fraction (SVF). It's a mix of platelets, growth factors, endothelial cells, T cells, red and white cells, and, of course, stem cells. Berman then injects that SVF back into the patient.

On a basic level, the procedure makes sense. Stem cells help repair tissues, so why not add them to damaged areas? The trouble is that beyond the basics, stem cells are far from understood. Scientists, for example, still don't know why a given stem cell will differentiate into one tissue and not another, or what prompts cell replication to turn on or off. They also can't predict when some stem cells will go rogue and turn into unwanted masses. Until scientists learn more, it will be impossible to say with complete confidence that any treatment comes without significant risk.

But studies are under way. In the past few years, a number of clinical trials have launched to explore cell-based therapies for strokes, spinal cord injury, and Parkinson's disease, among other disorders. The FDA is studying eight lines of adult stem cells for their ability to repair hearts, bones, and cartilage. It also recently

WARNING
STEM CELLS CAN TURN INTO OTHER TISSUES, INCLUDING MUSCLE, BONE, AND CARTILAGE, AND MAY FORM UNDESIRED GROWTHS IN UNEXPECTED LOCATIONS
REQUIRES LIPOSUCTION
THIS THERAPY HAS NOT RECEIVED FDA APPROVAL
STEM SC CELLS

PROP STYLING BY SARAH GUIDO-LAAKSO FOR HALLEY RESOURCES

cleared a cell-based multiple sclerosis drug for a Phase I clinical trial. That work is encouraging, but even so, there's a big divide between trials like these and safe, effective therapies.

Although already in use, SVF treatment has not yet bridged that gap. Berman still doesn't understand how exactly it works, which he openly concedes. His best guess is that it's not one factor. The stem cells in the SVF probably help repair tissue, but so do the growth factors and T cells. "These are complex processes, and we don't have the technology to pinpoint the exact mechanism," he says.

That's not to say Berman is doing anything illegal by offering a treatment he doesn't fully comprehend. He's not. He's not even doing anything unethical. He is healing patients who could not be healed. "People are indeed having amazing successes," says Anthony Atala, director of the Wake Forest Institute for Regenerative Medicine in North Carolina. But, Atala says, we need controlled studies to truly understand why. Until those happen, getting SVF is a little like gambling: You pay your money, you take your chances.

IV.

A few weeks after my MRI, I arrive for my experimental procedure at Berman's Palm Springs clinic. After I check in, Berman joins me in the waiting room. He tells me the first step is the stock-in-trade of plastic surgeons: a little liposuction.

He walks me to an examination room and asks me to lie on my stomach. He pulls up my shirt. With a needle full of anesthetic, he numbs my left love handle—no shortage of fat there, sadly. The drug is toxic to stem cells, he tells me, so he's careful to not inject it too deeply. Berman then makes a quarter-inch incision, inserts a small tube, and begins vacuuming. It doesn't feel like much, a light scraping, and there's a quiet hum. Within 10 minutes it's over. Berman places a Band-Aid on the wound and gives the fat over to a lab tech who will render it into the SVF. In about an hour, the sample will be streaming through my circulatory system.

The procedure seems effortless. Could it be so easy to get well? Many think not.

Leigh Turner, an associate professor at the University of Minnesota's Center for Bioethics, finds the various SVF therapies dubious. “No one has proved they’re safe or effective,” he says. “People are paying a lot of money for these treatments without any assurances.”

Paul Knoepfler, a biomedical scientist at the Institute for Regenerative Cures at the University of California at Davis, put a finer point on it: “This is a for-profit human experiment,” he says. Knoepfler maintains that stem cells could potentially form bone or cartilage in unwanted areas. He points to a case in Portugal in which a woman was treated with stem cells taken from her nose and implanted in her back to help cure paralysis. Eight years later, doctors found a lump of nasal tissue in her spine. In another case, a teenager treated at a Russian clinic with fetal stem cells for a nerve disorder ended up with a brain tumor. Neither treatment was SVF—and there is no direct evidence that SVF could lead to such results—but the risks can’t be ruled out. In one recent study in goats, SVF increased spinal inflammation and spinal disk degeneration.

Despite this, Berman argues that SVF is safe. “We’ve had a thousand patients and haven’t had any significant adverse reactions,” he says. He also records his cases and says he will post them online as studies at PubMed and ClinicalTrials.gov. A few years ago, he started something called the Cell Surgical Network, a group of about 50 doctors that includes cardiologists, radiologists, anesthesiologists, and neurosurgeons, all of whom offer SVF therapy. The more practitioners, Berman says, the more data they have.

Berman also points to the success of SVF therapy in other patients: racehorses. In the early 2000s, a company now called Vet-Stem began offering SVF to veterinarians, who can more freely use experimental procedures. One of those early to adopt it was Ross Rich, former owner of Arizona’s Cave Creek Equine Surgical and Diagnostic Imaging Center. “I was skeptical,” he says, “but I had some horses that were very expensive and couldn’t get them healed after 18 months.” Rich mentioned the treatment to his clients, and they wanted to give it a try.

“We injected the stem cells into the injured area, and three months later they were fully recovered,” he says. “I’d never seen anything like it. These used to be career-ending injuries, and now it’s like no big deal.” Vet-Stem claims to have treated thousands of horses successfully, and Rich has published studies that describe success rates of 80 to 90 percent. Plus, horses don’t experience a placebo effect. He was so convinced of SVF’s effectiveness that last spring, he and his wife got it for their back, knee, and ankle pain. Rich says they have seen dramatic improvements.

This comes as a comfort to me as I wait for my SVF to be prepared. I like the idea that a thousand people and thousands of horses have come before me incident-free. But I still have concerns. For one, most people treated with SVF received it only within the past several years. The long-term impacts of this therapy are still unknown. Also, it’s great that it has worked so well for so long in horses, but I’m not a horse.

> THE
> **NEEDLE SINKS IN DEEP.**
> SO THIS IS WHAT COMMITMENT FEELS LIKE, I THINK TO MYSELF.

V.

As I sit waiting for my fat to be centrifuged, I cannot help but perform a grim calculus. What’s worse: Living another year or 10 with chronic pain or undergoing an unproven treatment? I could still back out. I could, without explanation, walk out the door, hop in my rental car, and spend the rest of the afternoon sitting poolside at my hotel in Palm Springs. All I would lose is a little fat from my left love handle (and every bit counts). Once I get the SVF injection, there is no turning back.

About an hour after my liposuction, a nurse walks into the room with a vial of my SVF. She tells me the sample contains about 50 million cells, which is normal. Most of it will be applied through an IV drip, and then the doctor will inject some below my left shoulder blade. Am I ready? she asks. I pull up my shirtsleeve and offer my arm for the IV.

Almost as soon as the needle enters my forearm, a mix of stem and immune cells are coursing through my bloodstream. Because it’s unclear how the therapy works, Berman uses an IV drip to circulate the cells through the body. That way, they can attack inflammation wherever they find it. This seems a bit suspicious. Without genetic reprogramming, it’s unclear if adult stem cells from one tissue can target inflammation in another. I hope that I have not made a big mistake.

I sit with the drip for a while, and after about 30 minutes, an orthopedic surgeon named Jonathan Braslow walks in and asks about my back pain. I explain that it hovers between my left shoulder blade and my spine. Braslow seems familiar with the location and thumbs his way around until he finds the spot. “That’s it,” I say. “That’s where the pain is.”

“Okay, here we go,” he says. The needle sinks in deep. The tension in his arm releases as the SVF enters my shoulder. So this is what commitment feels like, I think to myself. Minutes later, I am out the door.

VI.

Although SVF therapy may be legal now, its future is murky. In December, the FDA released draft guidance concerning stem cells derived from adipose tissue. It was bad news for Berman. Typically, the agency regulates drugs but not surgeries. What distinguishes the two, at least in the case of biologic therapies, is the concept of minimal manipulation. If the patient’s tissue is removed and used in such a way that it retains its characteristics, that qualifies as minimal manipulation, and the procedure classifies as a surgery. If the tissue doesn’t retain its characteristics, the FDA deems it more than minimally manipulated, and the treatment is considered a drug. That means long and expensive clinical trials.

The agency’s draft guidance clearly states that stem cells drawn from adipose

CONTINUED ON PAGE 74 →

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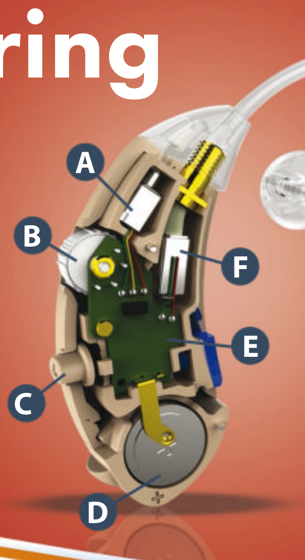

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EDITED BY ***Sophie Bushwick***

Manual

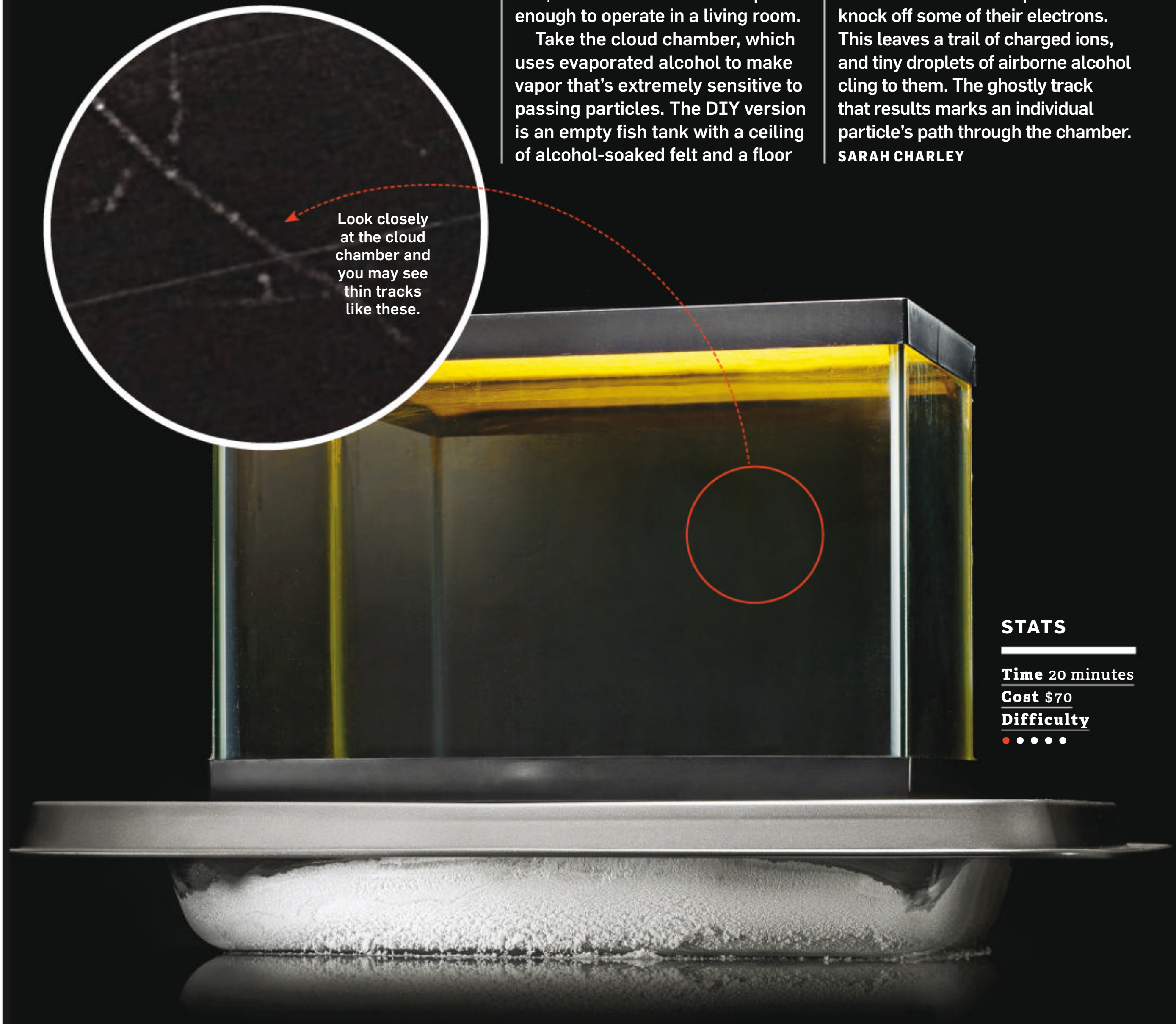
BUILD YOUR OWN PARTICLE DETECTOR

Machines designed to reveal subatomic particles operate on huge scales. Detectors at the Large Hadron Collider weigh thousands of tons, contain millions of sensors, and record particles moving at close to the speed of light. But they don't have to be so complex. In fact, some are small and simple enough to operate in a living room.

Take the cloud chamber, which uses evaporated alcohol to make vapor that's extremely sensitive to passing particles. The DIY version is an empty fish tank with a ceiling of alcohol-soaked felt and a floor of dry ice. The room-temperature alcohol at the top evaporates into the air and sinks toward the ice at the bottom. As it cools, it will condense on anything it can.

Cosmic rays are constantly crashing into Earth from space, and when they hit the atmosphere, they release a shower of particles. If one of these particles zips through the DIY cloud chamber, it will bump into molecules that make up the air and knock off some of their electrons. This leaves a trail of charged ions, and tiny droplets of airborne alcohol cling to them. The ghostly track that results marks an individual particle's path through the chamber.

SARAH CHARLEY



Look closely at the cloud chamber and you may see thin tracks like these.

STATS

Time 20 minutes

Cost $70

Difficulty

●○○○○

continued on page 66

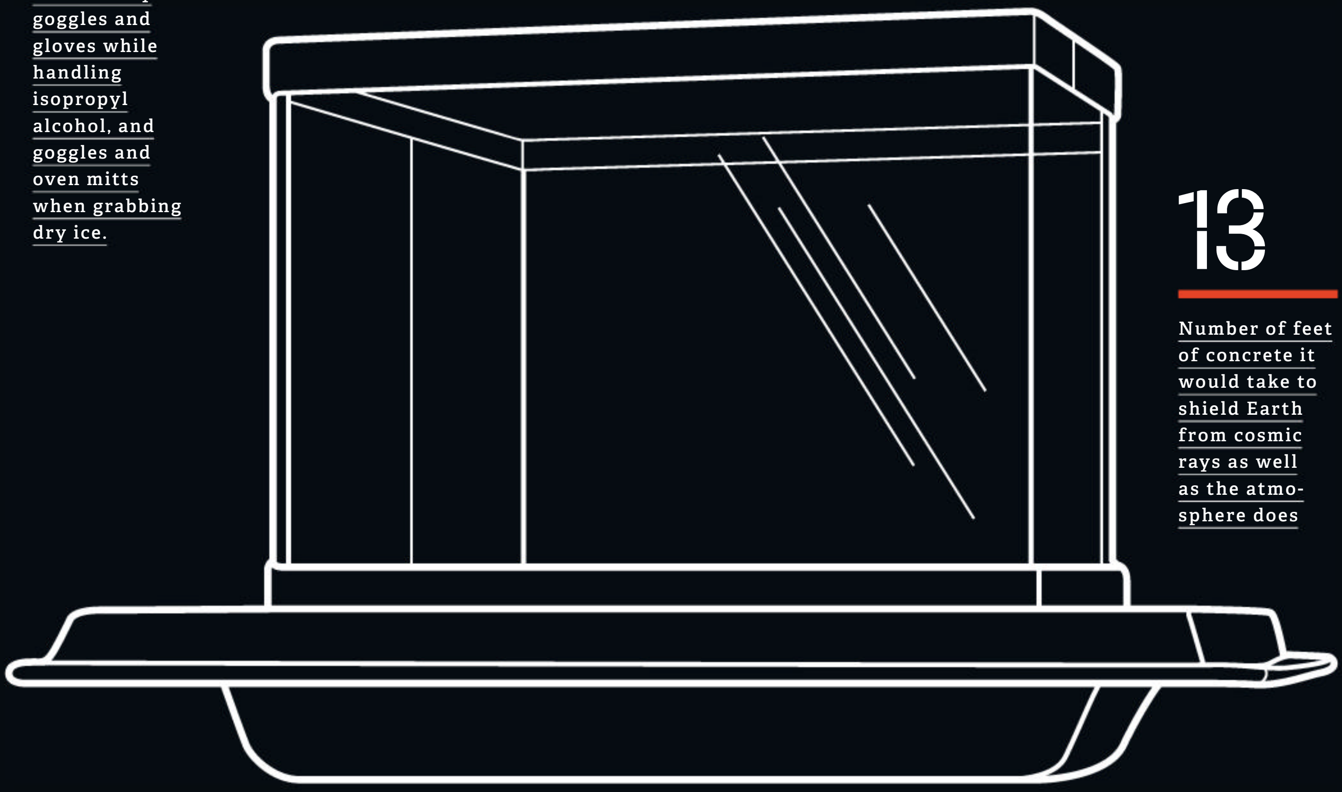
INSET: COURTESY SARAH CHARLEY

PHOTOGRAPH BY *Sam Kaplan*

Build It

continued from page 65

WARNING: Wear safety goggles and gloves while handling isopropyl alcohol, and goggles and oven mitts when grabbing dry ice.



13

Number of feet of concrete it would take to shield Earth from cosmic rays as well as the atmosphere does

MATERIALS

- Clear plastic or glass tank
- Felt
- Superglue
- Isopropyl alcohol, 90% concentration or more
- Dry ice
- Wide, shallow container for the dry ice
- Dark metal baking sheet (larger than the tank's mouth)
- Flashlight

TOOLS

Scissors

Safety goggles

Latex or nitrile gloves

Oven mitts

INSTRUCTIONS

1

Cut the felt to match the tank's footprint, and glue it onto the bottom (where the sand and fake treasure chests would normally go).

2

Put on your safety goggles and gloves, and pour enough isopropyl alcohol into the tank to saturate the felt. Drain off any excess.

3

While wearing oven mitts, place the dry ice in a shallow container. Cover it with the baking sheet.

4

Flip the tank upside down onto the baking sheet, so that the felt-covered bottom is at the top. You can use extra felt to block the seam between the tank and the tray. Now remove the goggles and mitts (but put them back on when disassembling the cloud chamber).

5

Wait about 10 minutes for the alcohol vapor to fill the tank. Then turn off all the lights and shine a flashlight into the tank.

6

If you see a track that looks like the path of a lost tourist in a foreign city, you're looking at an electron or a positron, the electron's antimatter twin. The lightweight particles bounce around when they hit molecules in the air, leaving zigzags and curlicues.

7

A short, fat track appears when an atmospheric radon atom spits out a bulky, low-energy alpha particle (a clump of two protons and two neutrons). Radon is a naturally occurring radioactive element, but its concentration in the air is so low that its airborne presence is less radioactive than peanut butter.

8

A long, straight track indicates that you've probably got muons, heavier cousins to the electron. Muons are produced when a cosmic ray bumps into a molecule high in the atmosphere. Because they are so massive, muons bludgeon their way through the air and leave clean lines.

9

If a track suddenly forks, congratulations! You just saw a particle decay. Many particles are unstable and will transform into more stable particles. You are watching physics in action.

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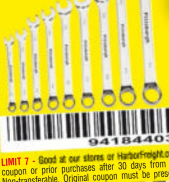

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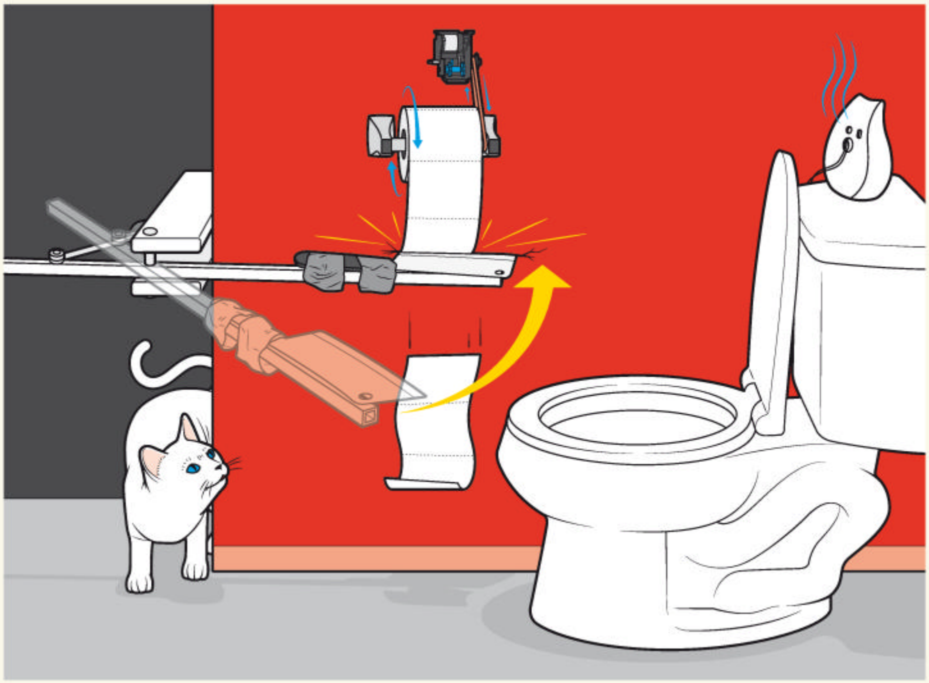
Theme Building

ABSURD ROBOTS FOR POINTLESS TASKS

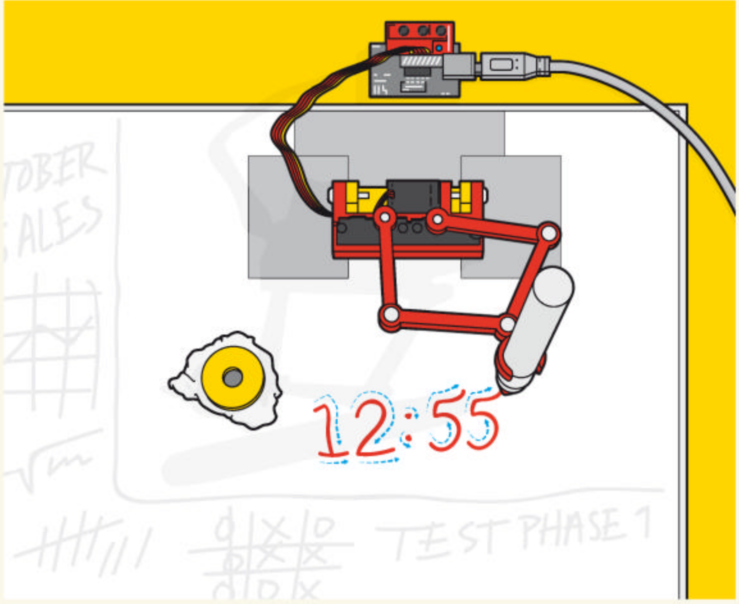
One day, robots will most likely take on many of our most mundane chores. No more folding of laundry or washing of dishes. But until that day comes, we'll have to settle for ones that take on less-necessary duties. These three ridiculous machines are masters of their utterly odd jobs.

CORINNE IOZZIO



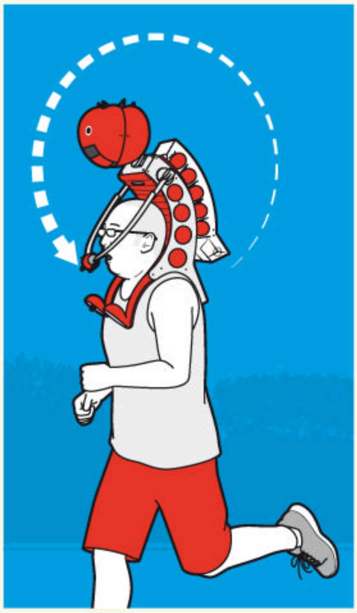
TOILET-PAPER PORTIONER

When Michael Nichols heard his neighbors arguing over proper toilet-paper portioning, inspiration struck. The Canadian software engineer—who builds Halloween animatronics for fun—decided his next project would be a machine that cuts an indisputable portion: exactly three squares. Pressing one control button unspools the toilet-paper roll. Pressing another triggers an air pressure–driven cleaver to swing through the toilet paper and into the wall behind it. Nichols also added an extra circuit linked to an air freshener. The method works well—as long as users stay clear of the chopping cleaver.



TIME WRITER

A few months ago, Google software engineer Maurice Bos decided to build a clock for his office in Zurich. A conventional one seemed dull, so Bos created a machine that scrawls the time on a whiteboard. Using a radio-frequency connection, a computer sends instructions to a microcontroller mounted on top of the board. That controller then directs an articulated arm to erase the old time and write the new one with a marker. The process takes about 15 seconds and repeats every five minutes.



TOMATO FEEDER

Marathon runners need energy on the go. Some chug Gatorade; others eat energy bars. Japanese tomato-product purveyor Kagome has another plan: It built the Tomatan, a shoulder-mounted robot that feeds runners tomatoes. The machine debuted at the Tokyo Marathon in February. It's activated by an onboard timer that signals one of six tomatoes to roll down a chute at the rear of the backpack. A pair of arms then grab it and lift it over the runner's head to his mouth. The flagship model weighs 18 pounds, though design studio Maywa Denki has also prototyped a 6.6-pound version called the Petit Tomatan. Lugging either quickly burns through the 132 calories six tomatoes provide.

1.6

Estimated weight, in pounds, of six tomatoes

ILLUSTRATIONS BY Chris Philpot

The Tricorder Comes Down to Earth

In *Star Trek*, a visit to the sick bay nearly always began with a scan of the tricorder, a handheld instrument that could quickly gather vital signs and diagnose ailments. Now 20 undergraduates and recent alumni at Johns Hopkins University are poised to bring the tricorder out of the realm of science fiction. If they succeed, they could change the future of diagnostic medicine, earn the adoration of Trekkies everywhere—and win $7 million.

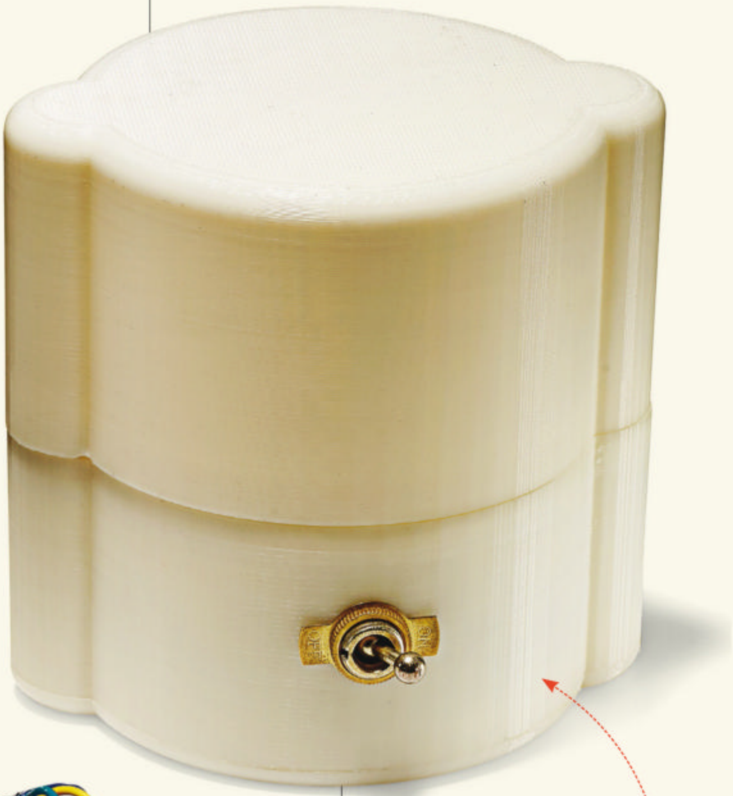
The current and former students make up Team Aezon, one of 10 finalists and the only university team remaining in the Qualcomm Tricorder XPrize competition. (“We wanted our name to sound cool and to start with *Ae*,” says 22-year-old team leader Tatiana Rypinski, “so we could appear at the top of the list alphabetically.”) The contest, which began in 2012, aims to generate a portable system that diagnoses 15 health conditions and monitors five vital signs, including temperature and blood pressure.

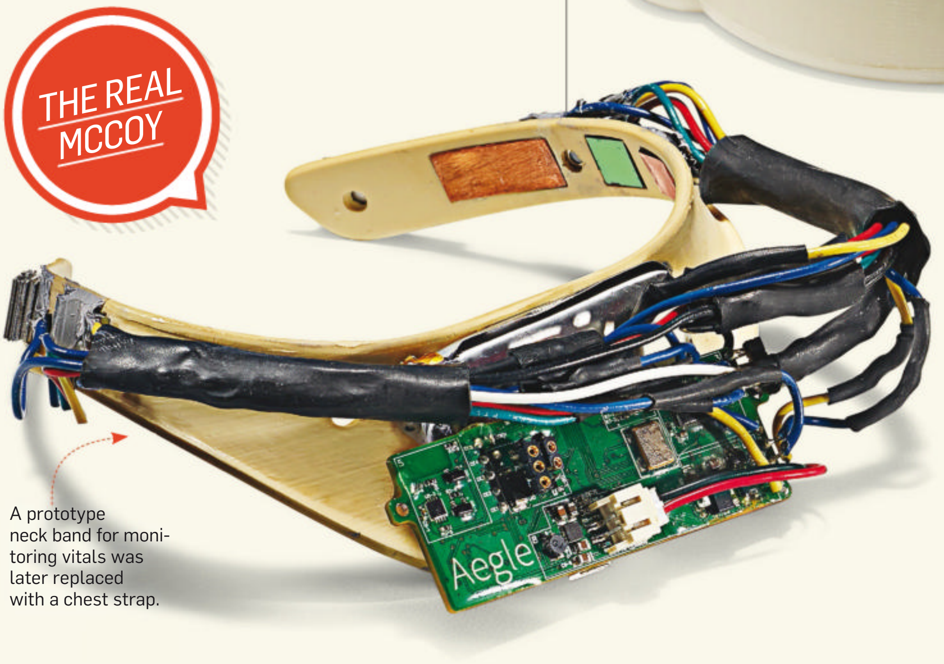
To get into the finals, the team members have had to meet multiple deadlines over several years—while maintaining a full course load. “Over and over again, we’ve had to tackle obstacles head-on and keep going,” says Rypinski. For example, the team’s first device for recording vital signs was a partially 3-D–printed band that fit around a user’s neck. It took a year to build, but making the band universally adjustable proved difficult. So they scrapped it entirely and replaced it with a chest strap.

79

Number of episodes in the original *Star Trek* series

The work ends in June, when finalists must submit 30 functional prototypes to the XPrize Foundation. Six months of user testing will follow, and the winner will be announced in January. Regardless of the outcome, the effort has been worth it, says team member Krzysztof Sitko, also 22. “As a student engineer, you really want to challenge this big romantic problem. You’re fine putting in sweat and blood with no return.” **ANDREW ZALESKI**





A prototype neck band for monitoring vitals was later replaced with a chest strap.

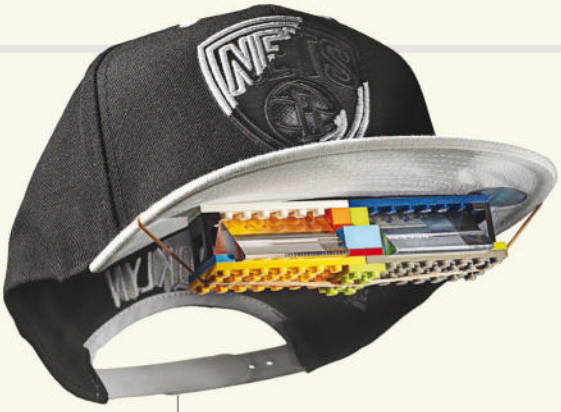
HOW IT WORKS

Aezon’s tricorder system includes a blood-pressure cuff and a chest strap that monitors body temperature, heart and respiratory rates, and oxygen saturation. It also comes with a lancet for collecting blood and a cup for urine. The user transfers the sample onto a disposable cartridge, then pops the cartridge into a “lab box” slightly larger than a coffee mug. The lab box diagnoses pneumonia, diabetes, and HIV, among other disorders, in less than an hour, and sends the results to Aezon’s smartphone app via Bluetooth.

PHOTOGRAPH BY Sam Kaplan

5-Minute Project

Turn the World Upside Down



Feel like dancing on the ceiling? All you need are some Legos and two prisms. The largest facet of a prism acts like a mirror: Light rays enter through the smaller sides and reflect off the big facet's inner surface, flipping an image vertically. Harness that optical trick with one prism for each eye, and you'll be walking around in your own upside-down world. **KATIE PEEK**

Thanks to reader Christopher Marley for the idea. Got your own 5-Minute Project? Send it to *manual @popsci.com.*

STATS

Time 5 minutes
Cost $20+
Difficulty
● ○ ○ ○ ○

MATERIALS

- Two right-angle triangular prisms
- Legos
- Hat with a sturdy brim
- String or rubber bands

STEPS

1 For each prism, place a four-stud baseplate upside down, centering the biggest side of the prism on top.

2 Build a brace on each side that matches the prism's height—a tight vertical fit will pin the prism in place.

3 Place a two-stud baseplate upside down on top, aligned so the right angle of the prism nestles between the two rows.

4 Place the two prism frames side by side and add another small baseplate to join them together.

5 Loop the string or rubber bands over the hat brim or crown, positioning each prism in front of an eye.

Killer App

ASTEROID DATA HUNTER

Want to protect the planet from asteroid strikes? There's an app for that. In March, NASA and asteroid-mining company Planetary Resources released Asteroid Data Hunter. The free desktop application is the culmination of the Asteroid Data Hunter Challenge, in which participants vied to create the best algorithm for locating individual asteroids. Stargazers submit their telescope photos to the app for analysis, and software compares the snapshots with images of known asteroids. If the app discovers a new near-Earth object, it helps users report it to astronomers for future tracking. **JUNNIE KWON**

PHOTOGRAPH BY SAM KAPLAN

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✓Yes
×No
✓Yes
✓Yes
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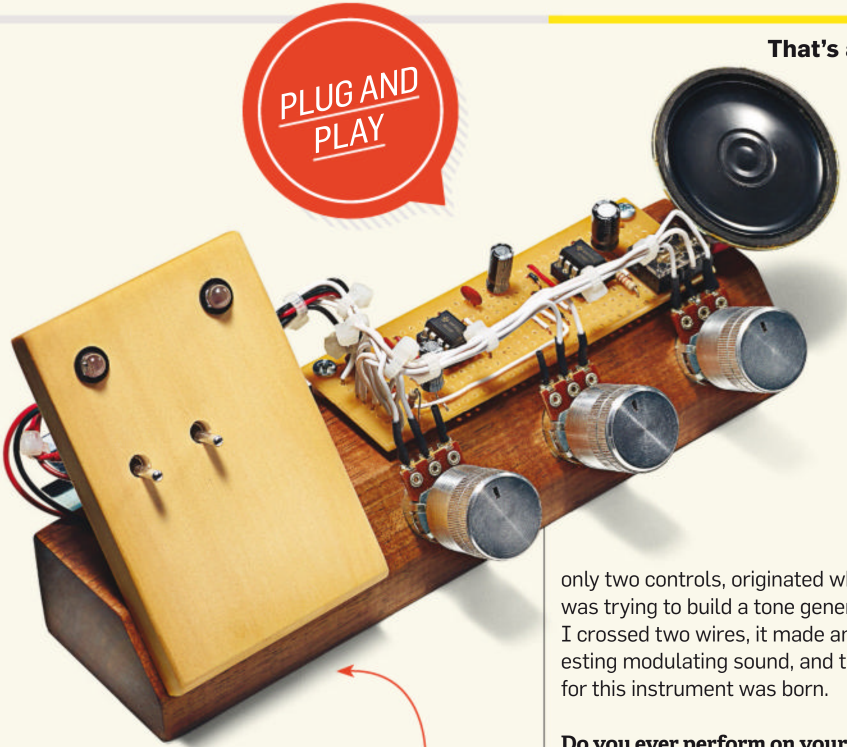
SYNTH LORD

Instead of gift-wrapping a store-bought musical toy, engineer Brian McNamara built a custom synthesizer for his daughter Rhianna's first birthday. "I designed the R-Tronic," he says, "a basic step sequencer you trigger by pushing wooden blocks into holes on the front panel." His daughter loved her present, and McNamara set about making more wood-based synthesizers simple enough for anyone to play. He sells the handmade instruments in his Etsy shop, Rarebeasts. **JEREMY COOK**

Why did you decide to design synthesizers full-time?
I wanted to be there for my kids before and after school. Electronics and instruments are my passion, so I just combined the two. I didn't realize I'd be selling so many instruments to experimental musicians.

What inspires a new instrument?
Sometimes there's a sound I want. Sometimes it springs from mistakes: The Wicks Looper, which allows you to build up loops very slowly with only two controls, originated when I was trying to build a tone generator. I crossed two wires, it made an interesting modulating sound, and the idea for this instrument was born.

Do you ever perform on your own products?
My solo act CupAndBow uses a lot of instruments that I've created, as well as commercial synths, for an ambient, experimental sound.



The Crownotron synthesizer has only four basic controls but can create a wide range of sounds.

PHOTOGRAPH BY SAM KAPLAN

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Go Ahead . . .

Ask Us Anything

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ANSWERS BY ***Daniel Engber***
ILLUSTRATIONS BY ***Jason Schneider***

Q: WHY DOES MOLD COME IN SO MANY COLORS?

Short answer Pigments offer protection.

A:

The amazing diversity of colors produced by molds and other fungi can vary regionally, says Sara Robinson, a researcher at Oregon State University. Blues and greens are prevalent in the Pacific Northwest, whereas oranges are more common in the Amazon. But the *raison d'être* of this rainbow of melanins, carotenoids, and other pigments isn't always clear.

Some of the species Robinson studies secrete melanins that act as weapons against enemy fungi; some lay them down as barriers that rival molds can't breach. Other labs have found that pigments can protect fungi from ultraviolet light, temperature extremes, and free radicals.

Nicholas Money, a fungal biologist at Miami University in Ohio, has studied how fungi cope when engineered without their normal melanin. "They're pathetic," he says. "Their list of disabilities is so long that it's difficult to focus on any one problem." Fungal melanin may have evolved to protect against enzymes produced by amoebas in the soil. Even though melanized fungi, as a rule, are heartier and more prolific than other kinds (which may explain why "black molds" have such a bad rap), there's no evidence that these species are more harmful to humans.

Still, the variety of colors and their functions remain somewhat enigmatic. "Fungi are investing a lot of energy into producing all that pigment," says Money. "They look beautiful and we don't always know why."

Q: Can you get a smell stuck in your head?

Short answer Sort of. Call it a noseworm.

A:

At some point, most of us get earworms—catchy tunes that play over and over in our heads. The same cannot necessarily be said for "noseworms," or catchy smells.

Some people with conditions such as schizophrenia or migraines have reported hallucinating smells, says psychologist Avery Gilbert. "They're categorically negative smells," he says. "People aren't normally hallucinating flowers." In one 2013 study, researchers described a Parkinson's patient as suffering from an imaginary "smoky burnt wood [odor] which changed to onion-gas and then to a noxious skunk-onion excrement."

Gilbert has also researched the deliberate conjuring of smells in the mind. He has found that professional noses—paid fragrance experts—are better than the rest of us at imagining aromas. Other studies suggests that people who report more vivid apparitional smells are also more likely to experience odors in their dreams.

A true noseworm, if it exists, would be something different. It's possible that when you get a whiff of something weird, such as castoreum (a secretion from beaver butts), a snapshot of the odor sticks with you. That might be because the fragrance has clung to your shirt or your nose hairs, Gilbert says, or it could be a kind of "mental resonation" that "sticks in your nose, and you keep smelling it throughout the day." P/S

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CONTINUED FROM PAGE 62

tissue are more than minimally manipulated. Enzymatic digestion and separation by centrifuge leaves doctors with something very different from plain old fat. According to Turner, the bioethicist at the University of Minnesota, the FDA position is a strong signal of coming regulation. But when that will arrive is anyone's guess. For now, SVF clinics are in the clear. "Draft guidances are not legally enforceable," he says. "If you were to extrapolate from the past into the future, I'd say we're going to see more of these clinics."

When I reach Berman by email after the FDA announcement, he's unfazed. "The entire purpose of the FDA mandate is to prevent the transmission of communicable disease," he writes. "Since everything we use is FDA-approved, even if not approved specifically for making SVF, as surgeons, we can do whatever we want as long as there's no risk of disease transmission."

While things get sorted out, Berman says, the Cell Surgical Network is building a cryogenic library where patients can store stem cells, much like women store reproductive eggs. As we age, we lose stem cells. Wouldn't it be nice to dip into a stock of frozen ones to save a limb or stave off crippling arthritis? "I think transplants will be a thing of the past," says Rich, the veterinarian. "In the future, you might be able to call a company that has the best stem cells for the damaged body part and have them overnighted."

VII.

A week after my SVF, I'm at home working when I realize that, for the first time in seven years, I have no back pain. I just feel normal. On various stem cell–related sites, I've seen plenty of warnings that improvements to a condition may not be the result of a stem cell treatment. Relief can come from some mixture of the placebo effect, concurrent therapies, and natural healing. But I hadn't had a placebo effect from any of my other treatments, I haven't been doing any other therapies, and I hadn't healed naturally in seven years.

Then I drive from New York to Maine. Long drives were always my Kryptonite, and sure enough, by the third hour of the six-hour ride, I can feel my old pain begin to return. I try not to think about it, but it is there. I feel defeated, and I call Berman a few days later. He tells me to stay positive. "Sometimes it will come back a bit and then go away again," he says. "You just have to give it some time."

Slowly, the pain subsides. While it pops up every now and again, it disappears just as quickly. Then, about three months after my treatment, it seems destined to never return, no matter how long I drive or how much I exercise. It's just gone.

At this point, it's been nearly a year, and I'm pain-free. Still, I worry that it's all just temporary. I recently heard from Lamon Brewster, the boxer. He said his recovery had inexplicably failed, leaving him blind in his left eye once more. "It just reversed," he says. While Brewster is the exception and not the rule among the SVF patients I'd spoken with, his case is an important reminder of something I try not to think about too much: When you sign up to be a guinea pig, nothing is certain, and only time will tell. P/S

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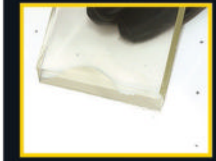

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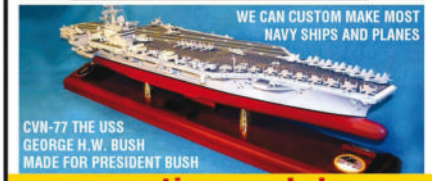

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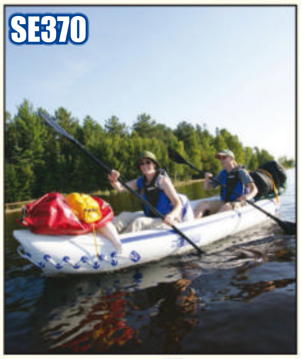

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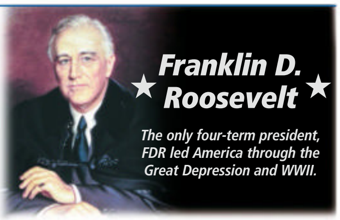
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From the Archives

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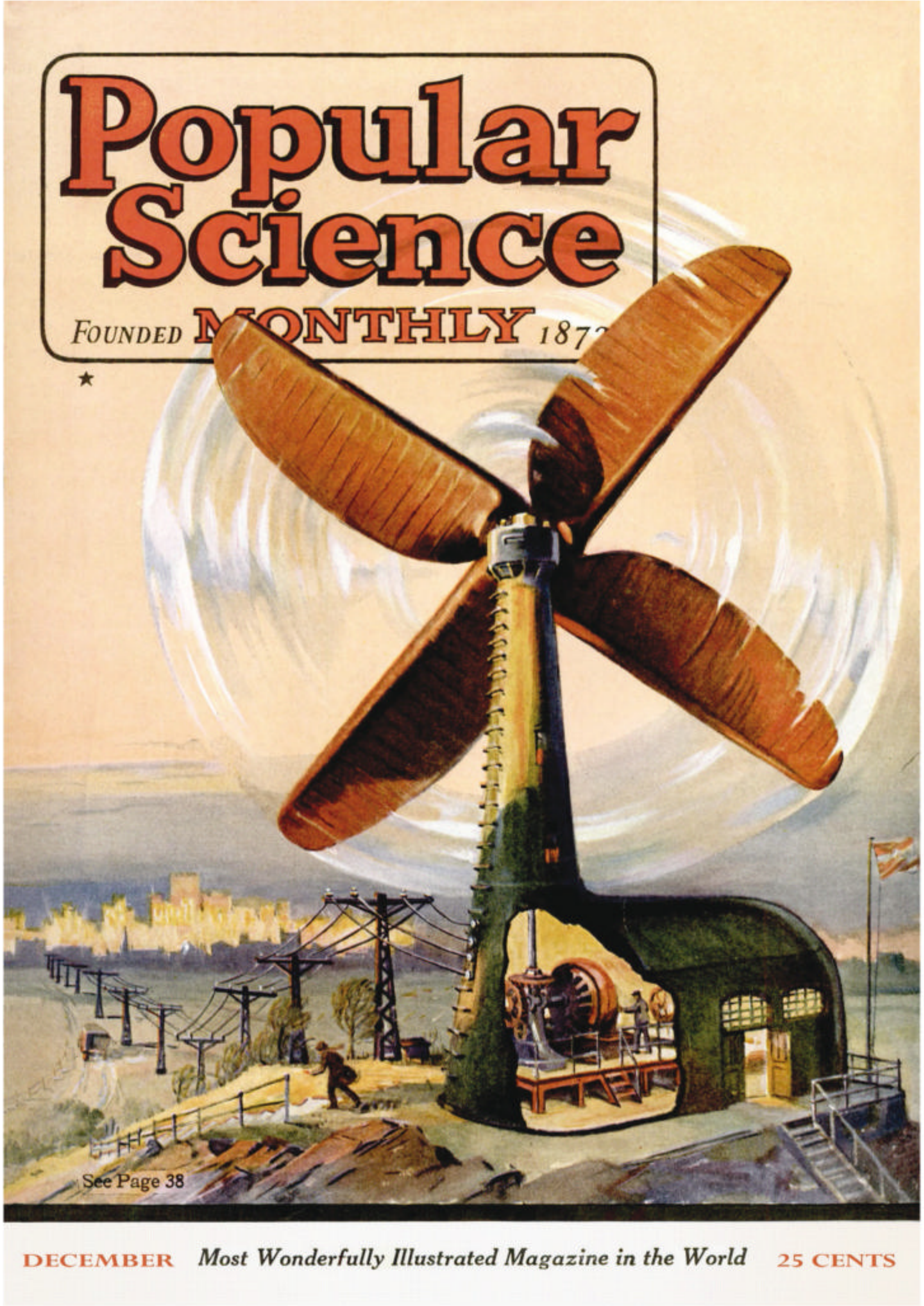
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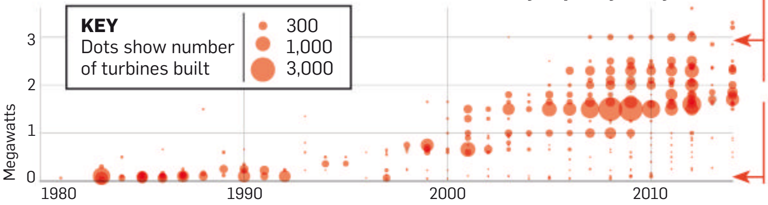
08

Megawatts of capacity of the world's most powerful wind turbine, which went online in 2014

SLOW GROWTH FOR HIGH-POWER TURBINES

When blades started spinning on the first U.S. wind farms in the 1980s, turbines were capable of producing up to a few hundred kilowatts. Today, turbines are 10 times more powerful, but typical capacity has plateaued. **KATIE PEEK**

Number of new land-based turbines installed in the U.S., by capacity and year



Larger turbine development has leveled off, partly due to cost constraints.

Small turbines, while less prevalent, still power homes, farms, and schools.

SOURCE: ELECTRICITY MARKETS AND POLICY GROUP, LAWRENCE BERKELEY NATIONAL LABORATORY

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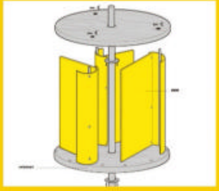

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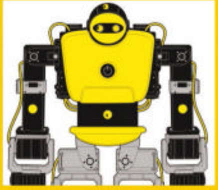

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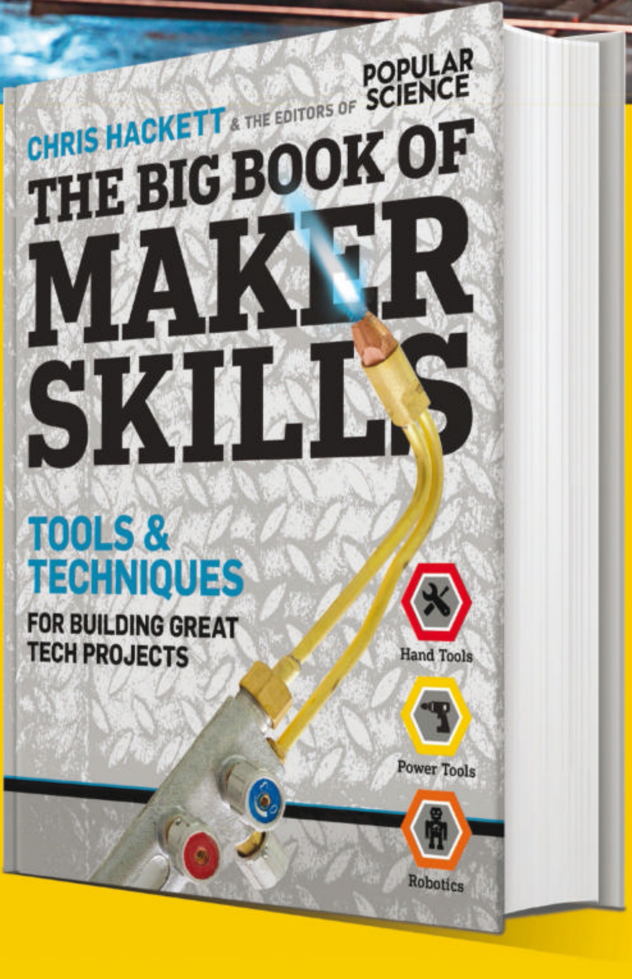
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